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...page 86

Preview of Nuclear Congress and Atom Fair...page 94

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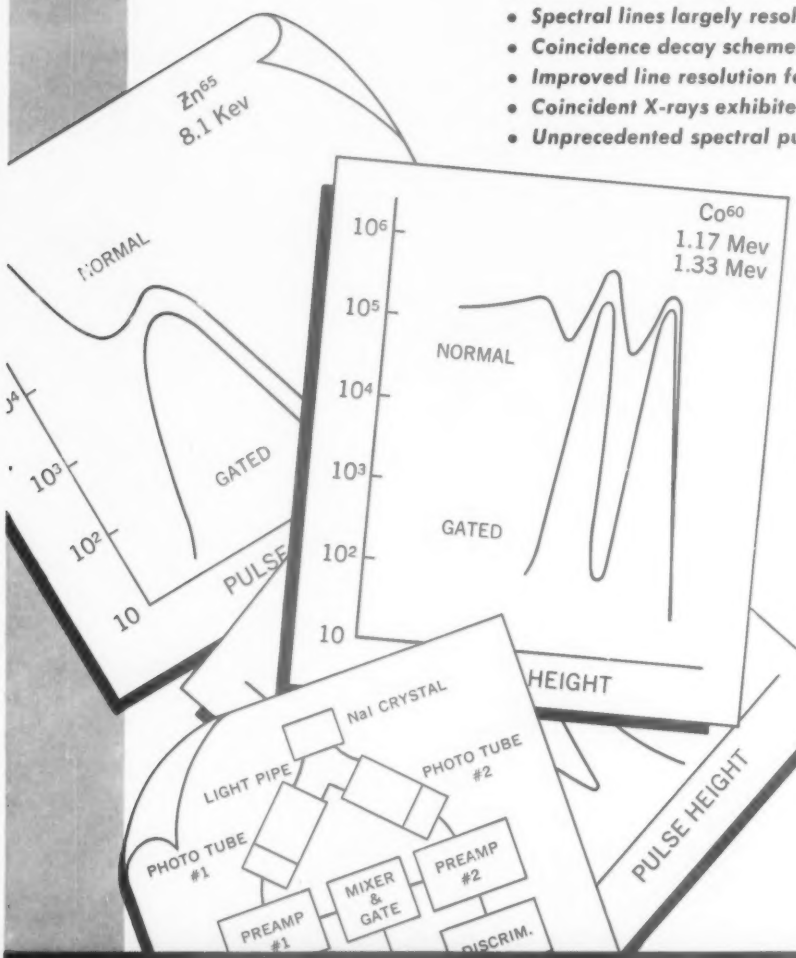

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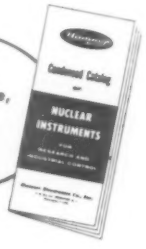

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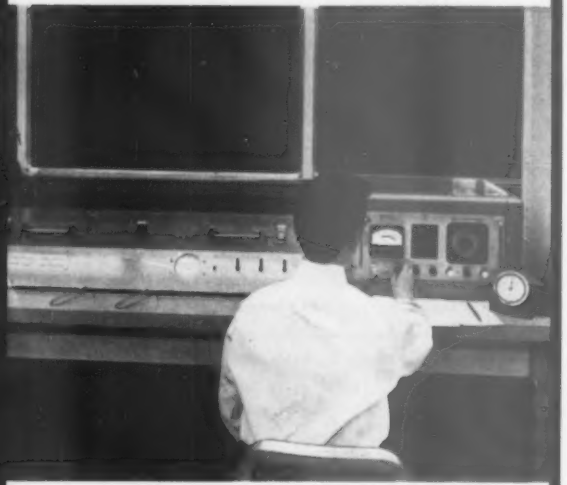

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Feature Articles

Reactor-Containment Engineering—Our Experience To Date — R. N. BERGSTROM and W. A. CHITTENDEN — 86

1959 Nuclear Congress and AtomFair — 94

Transistors Shrink Contamination Detectors — W. G. SPEAR — 97

IRL Reactor Goes Critical — 102

Data Sheet No. 31—Computing Aid for Reactor-Kinetics Equations — HENRI SMETS — 104

Yugoslavian Criticality Accident, October 15, 1958 — 106

Los Alamos Criticality Accident, December 30, 1958 — 107

Instrumentation and Measurements

Portable Tritium Monitor Has Gamma Compensation — J. D. ANTHONY — 110

Coated Semiconductor Is Tiny Neutron Detector — R. V. BABCOCK, R. E. DAVIS, S. L. RUBY, K. H. SUN and E. D. WOLLEY — 116

Gamma Spectrometric Assay of Fission-Product Kr^{85} — H. W. ALTER — 124

Simple Liquid-Sample Changer — NATHAN B. FRUCHTER — 126

Nuclear Engineering

Gaskets for Reactor-Plant Service — 128

Reactor Roundtable—Flowable Solids Reactor — M. R. DUSBABEK — 132

An Evaluation of UO_2 Dispersions — E. N. MAZZA and W. R. WEINBERG — 137

Applied Radiation

Irradiating Sewage Might Improve Bacterial Nutrients — 140

High-Level Dosimetry By Luminescence Degradation — FRANK H. ATTIX — 142

Safe Source for Gamma Absorption Measurements — 149

Departments

LETTERS	6	PRODUCTS AND MATERIALS	166
ROUNDUP	17	INDUSTRY NOTES	176
EDITORIAL	85	NUCLEAR CAMPUS	177
THERMONUCLEONICS	157	NEWSMAKERS	178
BOOKS	158	NUCLEAR CALENDAR	180

More about NUCLEONICS on next page ▶

About NUCLEONICS

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NUCLEONICS is looking for an engineer with working experience in reactor technology to add to its editorial staff. Since you may be the man we are looking for (or may know such a man), we'd like to tell you a bit more about the qualifications we desire. We'd like an engineering graduate who has had direct experience with the components end of the nuclear business. Perhaps he has helped specify valves for a primary-coolant system or maybe he has done design and specification work for heat-transfer equipment. Experience as an editor is not important in itself, though we wouldn't be surprised to find that our man had worked on his college engineering magazine or at least enjoys writing and has some feeling for what good writing should be like. We feel we have a lot to offer here at NUCLEONICS—it's an exciting and busy life that permits you to get a broad view of developments in the nuclear field. (For more detail on just what our editors do, you might want to look back to this department in the May 1956 issue.)

If you fit the above specifications, or if you are so good that you think we'd want to bend our specifications to meet yours, please write The Editor, NUCLEONICS, 330 West 42nd Street, New York 36, New York.

Containment

Nothing symbolizes a nuclear power plant so clearly as its containment shell. Though some have questioned the need for containment, all would agree that any containment shell that is built should be built soundly. On the other hand, containment shells are expensive and any economies that can be effected in their construction are welcome indeed. From a wealth of reactor-containment engineering experience authors Bergstrom and Chittenden have assembled the review on p. 86—we commend it to your attention.

Nuclear Reactions

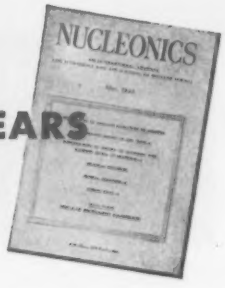
On the page after next, under the heading "Nuclear Reactions," you will find our revamped "Letters" department. The "Letters" department used to be located some place in the back of the book, and that may be one of the reasons why we didn't often enough get the lively exchange of opinion that one would like in a forum of this kind. We hope that more of you will emulate the three gentlemen whose contributions we carry this month and give us a piece of your mind.

Cleveland Again

As our high-information-density story on the upcoming Nuclear Congress and Atom Fair points out, the nuclear industry has met in Cleveland before—in 1955 to be precise. This year, as in 1955, NUCLEONICS will be among those exhibiting at Cleveland. Our booth number is 607. To find your way, use the handy tear-out map that is located on page 97.

—The Editors

10 YEARS AGO



Crystal counters. Diamonds were a nuclear physicist's best friend ten years ago—they were one of a group of crystalline solids whose enhanced pulsed conduction when irradiated gave promise of being a very useful particle detector. Among the advantages noted in a comprehensive review article were small size, low resolving time, high stopping power and high ionization efficiency. Since not all diamonds counted and since there was at least some evidence that the best counters were those of gem quality, (and hence expensive), there was an inevitable trend to other crystalline materials—zinc sulfide, silver halides, and cadmium sulfide among them. But none of these conduction counters were as successful as the scintillation devices that also came into vogue in 1949, and crystal counters have been relatively unimportant since.

A renaissance may be in order now that semiconducting crystalline devices are available—the article on p. 116 of the present issue, clearly demonstrates that some very interesting detectors can be made from germanium or silicon junction devices.—Robert Hofstadter, NUCLEONICS, April '49, p. 24.

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Coming Features in NUCLEONICS

Next Month

Report on First International Fuel Element Symposium

NUCLEONICS Reactor File No. 7—France's G-2

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NUCLEAR REACTIONS

Mr. Chips at Calder

DEAR SIR:

In the February 1959 edition of NUCLEONICS, on p. 27, there is an article headed "School Days . . . at Shippingport." The last sentence of this article says that it is believed that the Shippingport course is the only one of its kind anywhere offering operational training at a full-scale nuclear plant. I thought you might be interested to know that we have been running operational courses, mainly for British students but also for those from overseas, at Calder Hall Nuclear Power Station for the past two years.

—K. J. FROST, *Manager*
Calder Operations School
Calder Works, Seascale
Cumberland, England

Accident in Yugoslavia

DEAR SIR:

Your thoughtfulness in sending me a copy of the report on the Yugoslavian accident [this issue, p. 106] is greatly appreciated. The information contained in this report is more systematic and complete than what we have and is not inconsistent with any of the scattered data in our files. I'm afraid we have nothing of importance to add to this account.

You are to be congratulated on securing this story. It is a real service to the whole industry to have such an account and those on other accidents that you have been able to carry.

—CLIFFORD K. BECK, *Chief*
Hazards Evaluation Branch
U. S. Atomic Energy Commission
Washington, D. C.

[EDITOR'S NOTE: *A copy of the accident report included in the article starting on p. 106 of this issue was sent to Dr. Beck for his comment.*]

A Program for Safety

DEAR SIR:

I wish to express my personal belief that the article "Statistical Analysis of Reactor Safety Standards," by Ernest Siddall [NU, Feb. '59, p. 64], failed to state the case for safety improvements in the reactor field.

The fundamental fact of industrial safety is that every serious accident costs more in injury compensation, delay, damaged equipment, etc., than the supervisory forethought, selection and training of personnel, planning, and equipment that would have prevented the accident. The fear of a "safety-at-any-cost" program has not prevented many successful companies from maintaining superb safety records. Instead, industrial safety seems to come as a component part of good management. A poor safety record is one measure of poor management.

Statistical analysis of accident rates can be used in either a positive or a negative way. If used in a positive way, statistical studies can provide a basis for comparison between various industries as well as standards for each industry and factory. Establishments having poor safety performance can be singled out for corrective action if adequate safety statistics are available.

A negative use of safety statistics would be to excuse accidents on the basis that the industry as a whole is satisfactory. The fallacy of this approach can be illustrated by the Texas City, Texas, disaster where the industries involved (petrochemicals, transportation, etc.) were statistically above reproach. To overlook potential or actual safety hazards because of statistical average performance of an industry would fall in the same plane as a legal system that overlooks crime as long as the rate is low.

Safety statistics clearly show that an undue number of accidents befall an accident-prone segment of the population. Likewise, if one lists the reactor excursions that have been reported in the last five years, he finds that there are sites that are prominent on this list, although other sites having somewhat similar risks have had no excursions. If one examines safety performance of the coal industry, he finds that most mines are safe, but he may wonder why the managements of chronically unsafe mines have not been indicted as criminals.

Reactor safety begins with a state of mind. This state of mind is difficult to achieve. In spite of Christian indoctrination from cradle to grave, many of us fail to realize that sinfulness is characteristic of mankind. It will inevitably show up as shortcuts in design and construction of containment structures; as favoritism in hiring and promoting employees; as poor maintenance; as reckless operation; as laxity, cheating, and misrepresentation.

The other fields involving great public hazard, such as foods and drugs, medicine, engineering, transportation and public utilities, have accepted steps similar to those listed below. These are offered as a beginning toward a safer reactor industry.

1. Registration of qualified designers and operating personnel, with minimum requirements based on examination, training and experience.

2. Periodic re-examination of personnel and facilities.

3. A seniority program to reduce personnel turnover.

4. Civil service act for all governmental employees involved in licensing, regulating, financing or evaluating safety features of reactors.

5. Standard codes covering location, construction and operation of facilities.

The equipment with which a reactor may be safeguarded is no better than the designer, the manufacturer or the operating and maintenance personnel who look after it. A mechanic or an instrument repairman may redesign in five minutes any piece of equipment that requires attention. Safety analyses and statistical studies may become obsolete with so little as the installation of a clip lead or the turn of an adjustment screw. A piece of equipment that has performed superbly for months is apt to become a hazard because of a servicing change resulting from vacations, rotation of personnel, promotions, etc.

There have been many indications of hazards in the nuclear industry. Need one begin with the victims who painted radium dials and review the entire list to prove that the need for safety inevitably precedes corrective action? If this were not true, there would have been no Chalk River, Los Alamos, Oak Ridge or Windscale incidents.

It is human nature to resist curbs; consequently, a fully effective reactor safety program may be years away. Meanwhile, the industry will have to experience a continued pattern of accidents ranging up to or beyond the magnitude established at Windscale. If an accident of the magnitude of the Texas City disaster should occur, the industry may lose the chance to develop its own safety program because of the demands of an aroused public.

—KARL E. PLUMLEE, *Physicist*
Argonne National Laboratory
Lemont, Ill.

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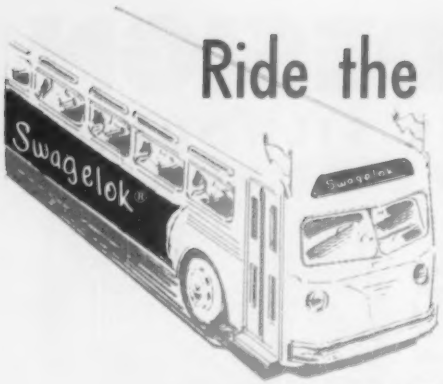

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Fred A. Lennon

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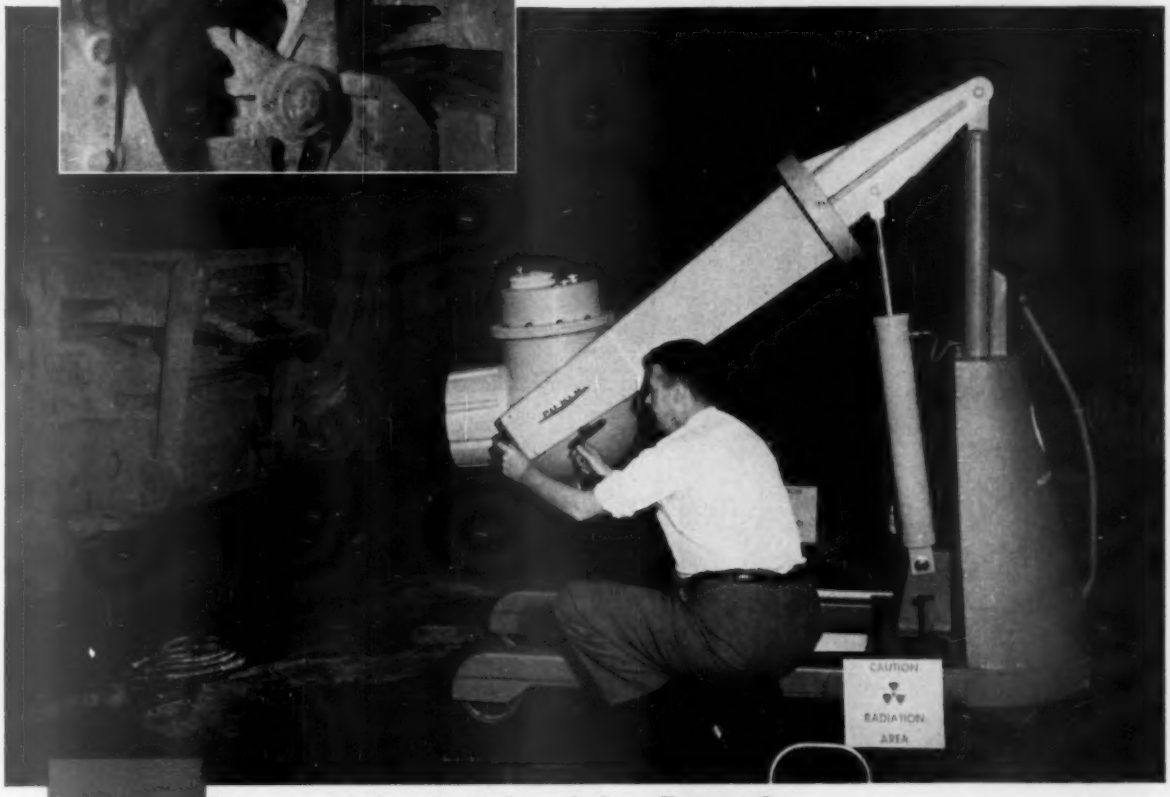

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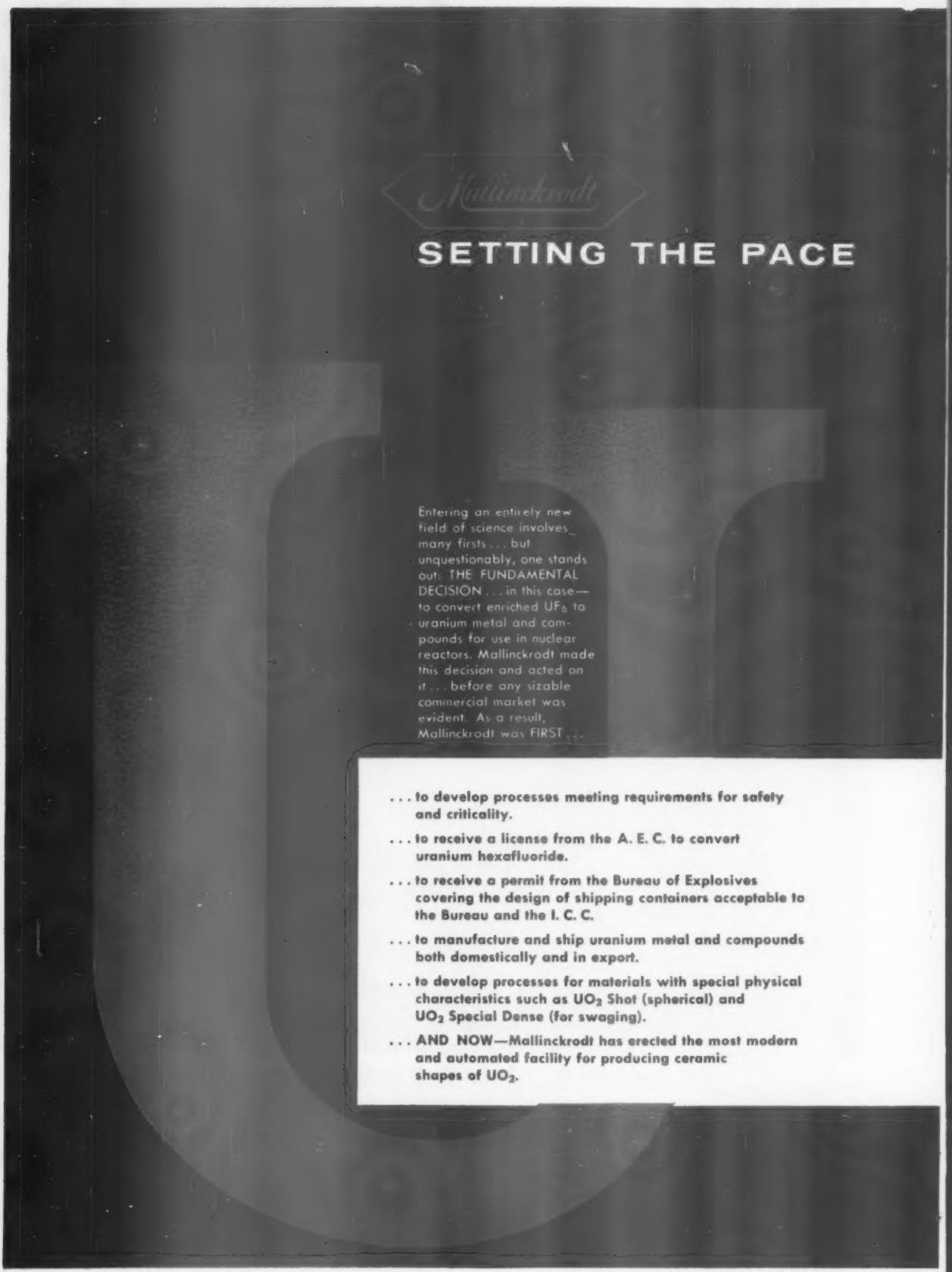
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. . . to develop processes for materials with special physical characteristics such as UO_2 Shot (spherical) and UO_2 Special Dense (for swaging).
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In 1956, Mallinckrodt became the first private firm to produce enriched uranium compounds for commercial uses. Since then, Mallinckrodt has processed more than 200,000 pounds . . . and has supplied fuel in research or production quantities for every private power reactor project in this country.

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Aerial view of Mallinckrodt's rapidly expanding plant at Hematite, Mo. Starting with 16,000 sq. ft. in 1956 . . . 4,400 sq. ft. were added in 1957 and 12,600 sq. ft. in 1958. The total 33,000 sq. ft. of plant area now devoted to the processing and handling of nuclear fuels. In addition, sales, administrative and analytical laboratory facilities are maintained in St. Louis.

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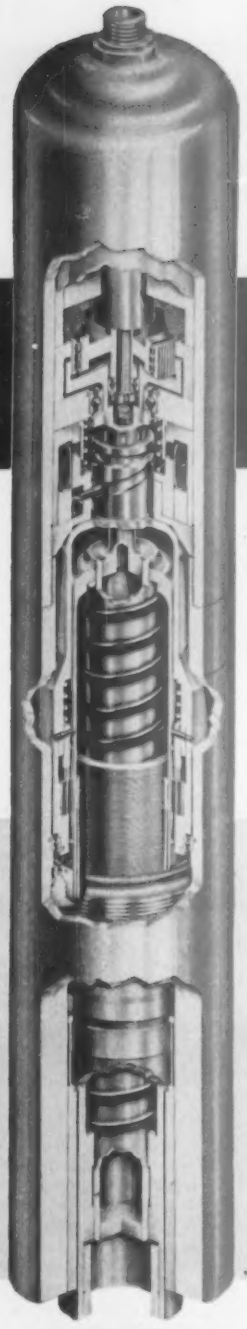

Reactor Components Systems

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We would welcome the opportunity to discuss your particular problems or requirements in the development of reactor components for your nuclear programs.

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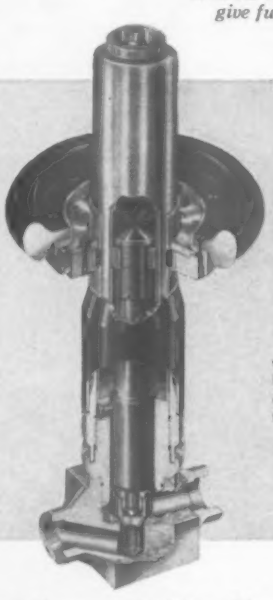

1 inch globe valve with a hand operated United Harmonic Drive actuator. The actuator is adaptable to motorized operation.

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In addition to design, development and manufacture of control rod drive mechanisms to your submitted specifications . . . United's continuing research has resulted in the development of the United Harmonic Drive principle — a method of transmitting power through steel walls by controlled deflection waves that produces positive linear motion. Using the new principle, the control rod drive mechanism wall is deflected within endurance limits of suitable materials, engaging the lead screw and actuating the control rod. The United Harmonic Drive principle gives precise motion control with positive position indication and offers mechanism and system cost savings.

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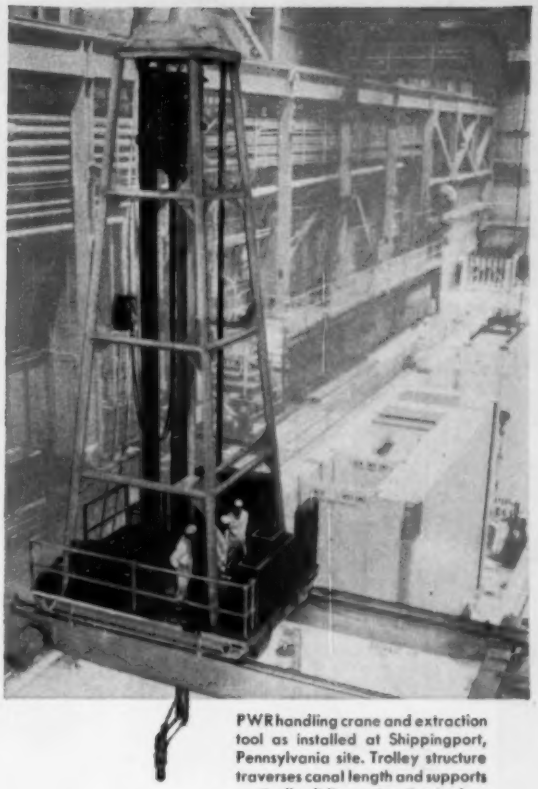


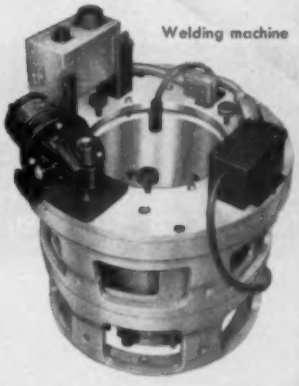
PWR handling crane and extraction tool as installed at Shippingport, Pennsylvania site. Trolley structure traverses canal length and supports vertically sliding extraction tool.

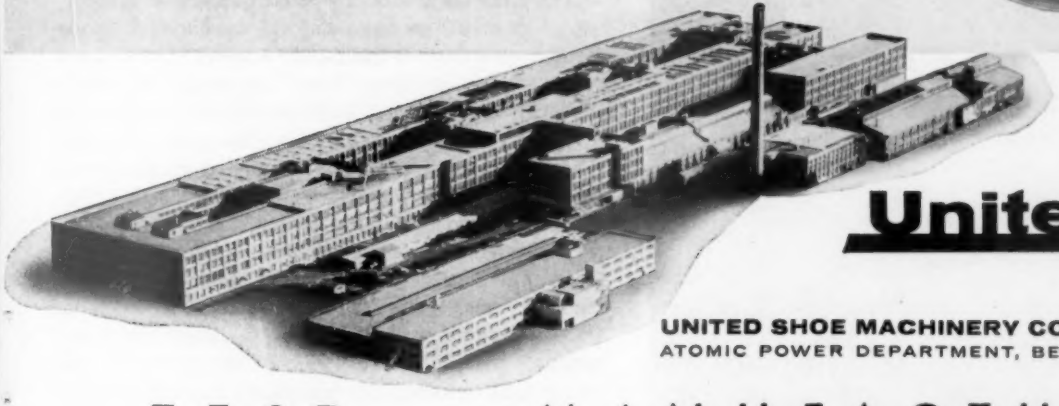
Cutting machine

SEAL WELDING AND CUTTING EQUIPMENT

The design and development of automatic seal welding and cutting equipment for nuclear reactors is an important activity at United. One such development involved the design and manufacture of cutting and welding equipment using consumable inserts for the U. S. Navy submarine Triton (S4G). Equipment will cut and re-weld 11 inch diameter welds on the control rod drive mechanisms at the various angles. A control unit provides automatic sequencing of welding operations and the design of the welding unit allows use in spaces as close as 1¾ inches from weld to adjacent mechanisms. Equipment can be operated with any or all control drive mechanisms in place and its reliability eliminates the necessity for radiographic inspection.

Welding machine





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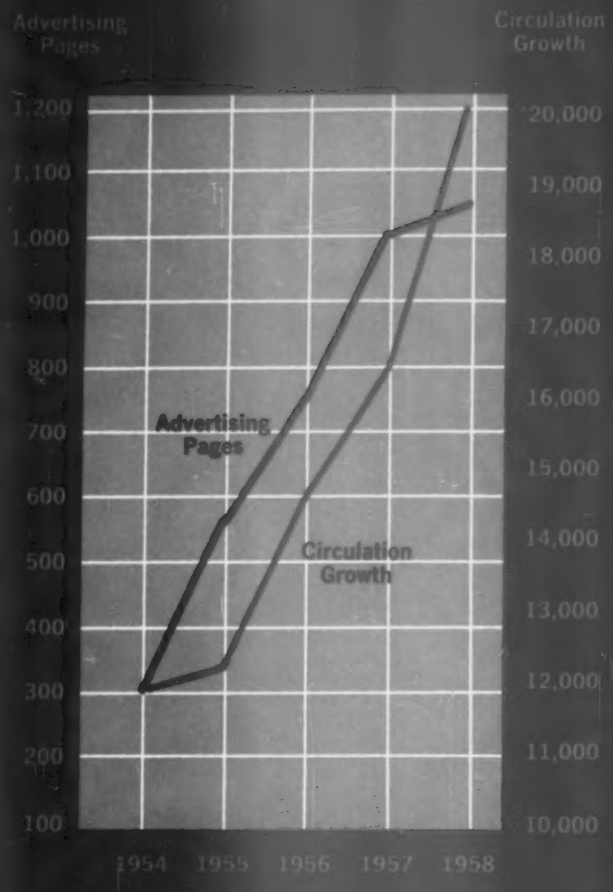
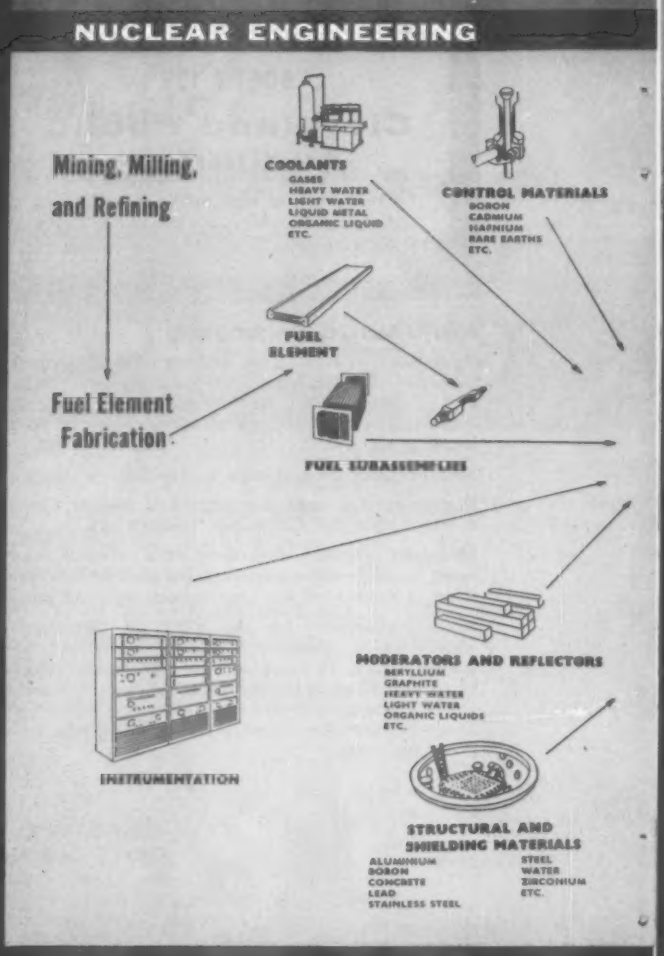


*According to June, 1958 Publisher's ABC Statement

ESTIMATED CUMULATIVE EXPENDITURES
FOR REACTOR, EQUIPMENT, FACILITIES

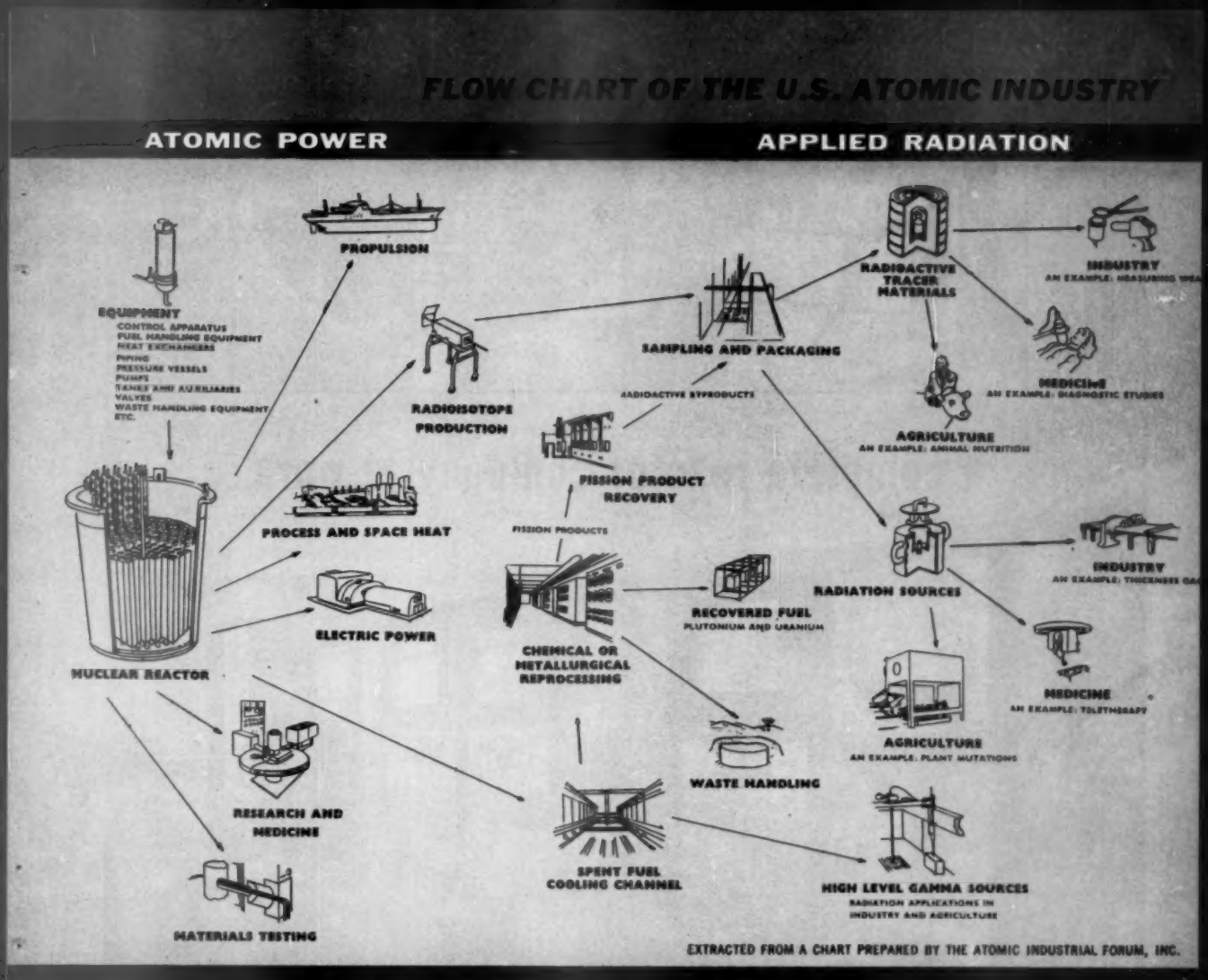
Source: NUCLEONICS, September 1957, p. 33



HOW NUCLE

Editorial

NUCLEONICS is a *horizontal publication* reaching across all industries employing the atom as well as the *vertical publication* of the nuclear industry. The editorial breaks down into three broad categories: ATOMIC POWER, NUCLEAR ENGINEERING, APPLIED RADIATION. Editorial excellence has made **NUCLEONICS** *the* authoritative voice in international nucleonics . . . officially recognized with FOUR Jesse H. Neal Editorial Achievement Awards. The first prize award was for a 58-page report on "Geneva Atoms-For-Peace Conference" in September 1955 . . . the second, for a 32-page report on the "British Calder Hall Power Project" in December, 1956 . . . the third "Nuclear Navy Paces Atomic Industry," in July 1957 . . . the fourth was won for editorials written by editor Jerome Luntz during 1957.



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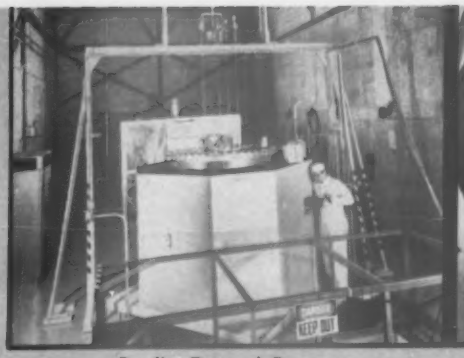

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ROUNDUP of Key Developments in Nucleonics

AEC, JCAE at Impasse Again on Reactor Policy

For almost two years the Democratic-controlled Joint Committee on Atomic Energy has been pressing the Atomic Energy Commission to reach formal agreement on a statement of long-range goals for the U. S. nuclear power program, plus a companion policy statement setting forth the means of achieving such goals. Effective agreement on goals was reached last summer (NU, July '58, 17), but AEC and JCAE are as far apart as they have ever been on the level and direction of the effort needed to meet those goals.

Furthermore, both sides reported last month that staff-level negotiations aimed at formulating a joint policy statement had not only come to a dead stop—but no resumption was in sight. In its essentials, the impasse was this:

- Negotiating teams led by General Manager Alvin Luedecke for AEC and Staff Director James Ramey for JCAE met once early in February, failed to make any progress, have not met since, and—on the AEC side at least—had no plans for resumption. As one top AEC official put it in mid-March: "It would be nice to have a document that both we and the Joint Committee could point to and say 'this is a program to which we both subscribe.' But it isn't likely to happen that way."
- AEC Chairman John A. McCone was standing fast with the fiscal '60 and long-range programs he described to JCAE in February (NU, March '59, 17). The long-range segment of the program contains some concessions to JCAE—spelling out five long-range goals, providing for a stronger AEC hand in construction of reactor prototypes and reinstating the second-round philosophy under which public power can sponsor reactor projects—but falls considerably short of Democratic demands. In fact, in its capital-subsidy offer for industry-sponsored prototypes, the program raises a new point of controversy.
- The Democrats, seeing the strong hand of the Budget Bureau in both short- and long-range AEC programs, have virtually abandoned hope of getting truly "joint" action. They can be expected, as they did last year, to add their own projects to the '60 reactor program and—this year—to propose certain lines of federal policy for the long-range.

As Congressional Democrats and the Administration (AEC and Budget Bureau) square off for another in their long series of contests, both sides emphasize it would be a mistake to attach much importance to the brief blowup between McCone and Rep. Chet Holifield (D-Calif.) during the 202 hearings in mid-February.

McCone took offense at Holifield's criticizing him before he had finished testifying on the AEC programs. But he apologized for any misunderstanding after the California Democrat explained he was criticizing AEC's proposed authorization bill, not McCone's testimony as such.

When hearings on the authorization bill opened a few days later, McCone seized the opportunity to note "there are no serious areas of disagreement." He predicted "we are going to come up with an agreed program that we are all going to be satisfied with." Holifield responded: "There is no reason why we can't."

The Democrats were particularly pleased at McCone's announcement that the proposed sodium-graphite reactor at Hallam will go forward after all (*see page 18*).

AEC took another conciliatory step by rewriting its authorization bill to include language clearly allowing a public power group to qualify for the small power reactor in AEC's '60 program under rules similar to those of the second round. The Commission would own the reactor and sell steam to the utility.

Accord Unlikely

Still, it appears unlikely that McCone is prepared—or able—to go far enough to make talk of a "joint" program realistic. Key Democrats fear McCone will be "inhibited by Budget Bureau restrictions" from publicly accepting anything that goes much beyond AEC's program. Says Holifield: "As far as I'm concerned, nothing is going to stop the Joint Committee from authorizing what it believes to be a reasonable and responsible program. I suspect what we'll end up with is something halfway between what the Committee wants and what the Administration is willing to accept."

Both JCAE Chairmen Clinton P. Anderson and Holifield charge the Administration with failure to plan for enough projects to follow those scheduled for the 1960–62 period, and they contend that the program faces a serious "loss of momentum."

"The Joint Committee," Anderson

Pressure builds to take regulatory role from AEC

A new JCAE-Administration debate broke out last month: Should AEC give up its safety and licensing roles in favor of either the U. S. Public Health Service or a new federal agency especially created for this job? The issue emerged from two weeks of JCAE hearings on radiation hazards and workmen's compensation.

The opening gun was fired by USPHS, which, with the support of a special advisory committee on radiation, has launched an intra-Administration campaign to assume radiation safety regulation for the federal government. Rep. Chet Holifield (D-Calif.) backed USPHS: "I believe the time has come when there has to be one body responsible in this field of protecting the public from the effects of radiation. From the traditional viewpoint, the Public Health Service should be that body." JCAE Chairman Anderson rhetorically asked an American Bar Ass'n. audience: "Have we reached the stage in development where AEC should be separated into two agencies (developmental and regulatory)?" Transfer of AEC responsibility for radiation measurement and safety standards to USPHS is now under study by the Budget Bureau.

has declared, "will want to consider additional projects both in terms of making modest advances on existing technology and also to proceed with promising reactor types through the prototype stage."

Holifield takes the position that AEC, under prodding from the Budget Bureau, is actually trying this year to hold net new authorization money as close to zero as possible—using cancellations, delays or modifications of previously authorized projects to offset new authorizations requested.

JCAE Reactors?

Since JCAE Democrats have made it clear they will not settle for the AEC proposals, the program enacted this year will probably be the result of a tug-of-war between the two sides—though it is felt that any tugging AEC does will be inspired by the Budget Bureau.

JCAE spokesmen feel that the chief area of maneuver between JCAE and the Administration will be five design studies due from the Commission in April and May—heavy water, nuclear superheat, large-scale pressurized water and boiling water, and intermediate-sized, organic-cooled reactors (NU, July '58, 22). Construction of one of these—the heavy-water reactor—has been recommended in a 70-Mw(e) size by the company handling design (Nuclear Development Corp. of America). Both AEC and JCAE assume that some construction recommendations will be forthcoming from the other design contractors.

"Commission reaction to these recommendations will be the test of their intentions," commented a JCAE source.

Chairman Anderson, in a Senate speech last month, offered his own reactor choices:

1. An intermediate-sized, organic reactor of 50–100 Mw(e) to prove out feasibility of larger versions. On this, AEC officials insist that the experimental reactor in their program, coupled with the Piqua project, constitutes all the work that can be done profitably on this concept at present. The experiment will enable the Reactor Development Div. to test its belief that a new moderator should be introduced, perhaps graphite.

2. A D_2O-moderated and -cooled, natural-uranium reactor. JCAE is studying the NDA design for its potential advantage over the 20-Mw(e) reactor projected by Canada. However, AEC is inclined toward the view that it would be unwise to spend scarce funds on a new D_2O project when three are already in the mill in the U. S. and the Canadians have promised full information on their experience.

3. Anderson has also mentioned two other reactors without specifying the types: "We may wish to consider assistance on a demonstration prototype for private construction in the size range of 75–150 Mw. We may also wish to consider an additional second-round proposal for a prototype in the 20–60-Mw range for construction in cooperation with a municipal organization or cooperative or other public body."

Finally, Anderson has listed a nuclear tanker among his favored projects.

Capital Subsidy Hit

Holifield, another JCAE power in his role as chairman of the subcommittee which reviews AEC's construction programs, questions two aspects of the AEC's position—the capital-grant proposal, which must be approved by Congress, and the gas-cooled arrangement under which AEC has accepted the Philadelphia Electric project and scaled down its own project.

In questioning the capital-grant scheme, Holifield is at odds with Sen. Anderson as well as AEC, because Anderson has thrown his support behind capital subsidies if made available for commercial-type reactors (NU, March '59, 78). Holifield, however, has complained that the government will not get the same patent rights from capital-subsidy support of an industry project as it gets from research-and-development support. He adds: "We should think a long time before adopting a corporate state philosophy. That is very similar to what Hitler and Mussolini did."

In questioning the gas-reactor situation, Holifield indicates skepticism of Philadelphia Electric's high-temperature reactor (NU, Dec. '58, 17), which, he feels, "leapfrogs" from the laboratory to a sizeable, power-producing prototype. He suggests that JCAE may want, instead, to authorize a smaller, intermediate reactor.

Budget Opposition

The Administration's preoccupation with a balanced budget (McCone has had to go to the President on some points of AEC's programs) has put some pressure on the Democratic leadership in House and Senate to tone down new-spending actions or face a "spender's label" accusation. Though this has affected the leadership's stand on spending legislation which has already come up this session (the housing and airport bills, among others), it has not impressed Holifield. He declares: "There are a lot of things more important than balancing the budget. It would be a catastrophe if the Russians score a major breakthrough on atomic power while we're busy balancing the budget.

"The Joint Committee is going to meet its responsibilities."

Hallam revived; Kiewit gets construction contract

AEC last month reversed itself on the Hallam project—deciding to go ahead on schedule after earlier announcing an indefinite postponement (NU, March '59, 17)—then selected Peter Kiewit Sons, Omaha, as construction contractor for the reactor. Atomics International is designing and procuring the nuclear system.

AEC offers development contract on superheat

AEC has invited industry to bid on a cost-type contract for engineering development work on reactor concepts and materials of particular promise in the nuclear-superheat program; included are fuel materials, steam-separation methods, and heat transfer. Proposals are due April 20 at Argonne National Laboratory.

Euratom plans 4,000 Mw by 1965; bid review starting

Euratom plans to complete 24 nuclear power plants totaling 4-million kw(e) in the next 5–6 years, according to Heinz Krekeler, a Euratom Commissioner. He placed cost at $1.43-billion, or $360/kw installed. Meanwhile, the U. S.–Euratom Joint Research and Development Board begins meeting early in April to consider proposals on hand under the 5-yr, $50-million research effort in support of the 1-million kw reactor program.

Industry Reports to JCAE: New Reactor Disclosed; Reprocessing Aid, Isotope Education Program Urged

This year as in past years, the "202" hearings before the Joint Committee reporting on the "development, growth and state of the atomic energy industry" revealed much industrial news in the atomic field. Some of the more important, among many, follow:

Wolverine Active Again

The Wolverine Electric Cooperative of Big Rapids, Mich., which has had one reactor project shot out from under it (NU, Oct. '57, 19; June '58, 25), disclosed it has been working actively with American Standard on its Variable Moderated Reactor concept, a refinement of the boiling water reactor, and plans to propose a prototype (capital cost: $350/kw) to AEC in the 5–50 Mw(e) range. American Standard explains the VMR as a boiling water reactor that is controlled by raising and lowering the level of the moderator water, thus eliminating all control rods. Elimination of control-rod openings in the top vessel head also permits commercial tolerances in manufacture of the vessel, for another large capital cost saving. The VMR is also "designed to accommodate nuclear superheat as soon as the technology of higher temperature and pressure superheated systems are developed": a superheater can be added to a VMR by core design change without affecting the moderator-level control.

American Standard Busy

In addition to its VMR development, American Standard also has been working on design of a process steam reactor for Michigan Chemical Corp. This would make steam for 85¢/1000 lb, about the same as current cost burning Michigan coal. John Linsenmeyer of Am-Stan suggested that AEC issue invitations for construction of a process steam reactor. He also disclosed that his firm is consolidating its atomic activities and doubling its staff at its Mountain View, Calif., labs.

Indian Point Delayed

The Oct. 1, 1959, earliest, and Oct. 1, 1960, latest completion date specified for the Indian Point reactor plant probably will not be met, James Fairman of Con Edison told JCAE; AEC is being asked to move back both dates by one year. "Our best prediction at the moment as to the actual date of operation is April 1, 1961," he said. Fairman disclosed—in discussing "the hardships of nuclear life"—that the total cost of Indian Point, first set at $55-million, then $75-million, and a year ago at $90-million, is now estimated at about $100-million; "the [newest] increase is almost wholly attributable to price escalation."

Reprocessing Co-op Program?

Fairman also recommended that AEC consider a demonstration program similar to the Power Reactor Demonstration Program for the nascent reprocessing industry.

"Such a program," Fairman said, "would involve development of a concept for a reprocessing plant to handle one type of spent fuel element and carrying this concept through the experimental stage to the construction of a prototype plant to be owned and operated by a chemical company or other appropriate industrial unit. Experience with a number of relatively small plants—each handling a different type of spent fuel and each operating at a good load factor—might well offer a short-range economic solution and also point the way to further progress. It could also be a method of encouraging industrial participation since smaller initial commitments by industry would be needed."

PWR Operation Lessons

The PWR at Shippingport has generated nearly 200-million kwh for Duquesne Light Co.'s grid and has made two power runs of over 1,000 hr without difficulty, John W. Simpson, Westinghouse vice-president, said. Its operators have learned about flux peaking, about the number of rods needed for such a reactor, about plate fuel-element behavior. Of the operating cost of $20-million/yr, Simpson said, only 10% or $2-million is operating cost in the normal sense; 45% is core cost for fabrication of additional cores, and 45% is strictly research and development. Thus far, he revealed, 110% of the design life of the seed has been used up (estimated for 3,000 hr, it has actually operated 3,300). The second seed will be similar to the first but will have boron burnable poison added, will be installed late this summer. Simpson said PWR could be duplicated today for considerably less than its $70-million building cost.

Sober Words from Sporn

Philip Sporn of American Electric Power Co. issued a word of warning about overemphasis on nuclear power. "Despite the optimistic projection of electric energy use and the assumption that nuclear power will account for over 75% of the increase in electric energy generation between 1957 and 2000, the part of the total energy requirements of all kinds that is likely to be satisfied by nuclear energy in that year is only slightly over 20%. This still leaves almost 80% of our total energy requirements to be supplied by conventional sources . . . I believe there is grave danger that so great an emphasis will be placed on atomic power development that we will tend to forget the essentiality of fostering continued development of an adequate supply of coal, oil and gas. I have reservations about the thesis that it is necessary to reduce the cost of nuclear power in this country to a point competitive with power from fossil fuels, in certain areas, within 10 years. While this would be a splendid achievement, it is not, in my view, an urgent necessity . . ."

Radiation Education

Emphasis of the testimony from radiation-industry witnesses was on education—education of management and the public on advantages of using radioisotopes. Samuel A. Auchincloss and Ronald A. Brightsen, presidents of Tracerlab and Nuclear Science and Engineering, respectively, warned AEC that it would not get the most out of its Isotope Development Program unless it took special steps to reach specific industry groups and show them how isotopes can be exploited in their fields. Said Auchincloss: "We are not getting through to enough of the [management] people who should use isotopes and whose wider use of them could produce vastly greater savings than we now enjoy." George B. Foster, vice-president, Industrial Nucleonics Corp., urged the Joint Committee to support a public education program. "Certainly," he suggested, "a broadened activity of public education on the facts concerning the radiological hazards of isotopes in relation to their benefits can be one of the most important contributions to the entire atomic program."

Bettis, KAPL Reorganized; Both Retain R&D Emphasis

The country's two huge Federally-owned, industry-built and -operated nuclear laboratories—Bettis and Knolls—have both undergone reorganization in recent months. Since the two (the Knolls Atomic Power Laboratory is better known in the nucleonics world as KAPL) are national laboratories in all but name and breadth of scope, any major organizational change affecting either is of significance to the nuclear industry. With both subject to shakeup recently, NUCLEONICS interviewed the heads of the two laboratories.

The two reorganizations are basically different: the one at Bettis is internal, the one at KAPL external. At the Westinghouse-built and -operated Bettis Lab at West Mifflin, Pa., on the southern outskirts of Pittsburgh, the project-by-project setup was dropped in favor of two project groups, a 4-man senior staff with broad powers, and five supporting departments. At Schenectady, where General Electric has built and operates KAPL, deputy director Bascom H. Caldwell took over the reins from Frederick E. Crever and will report to the Turbine division instead of the Atomic Products division of GE.

At Bettis

"We today have the challenge of improving what exists."

In these simple terms, John W. Simpson, a statesman of the nuclear power industry as chief of Westinghouse's Bettis Laboratory complex, explains the recent reorganization of his 4,800-man group and reveals what lies ahead as Bettis begins its eleventh year of research and development.

Having demonstrated at Shippingport and in the naval reactors program that nuclear power plants will work, Bettis has set about to make better ones—lighter, simpler, easier to maintain, longer-lived and cheaper.

"There's [still] a tremendous amount to do to fully understand reactors and make them work better," says Simpson. "What we do will be good, solid technical achievement—perfecting pressurized-water technology."

The Bettis reorganization—possibly because it has not been widely publicized—has prompted anxiety in some quarters of the nucleonics industry that this huge, respected team of scientists and engineers was being "broken up" now that the challenge of creating the world's first nuclear naval vessels and the U. S.' first commercial power station has been met.

This has been categorically denied by Simpson: "We have a big job in improving these reactors. The job is far from done, in any aspect of it you care to name. It's a good technological challenge, though it's clearly not the blue-sky challenge of building the *Nautilus*.

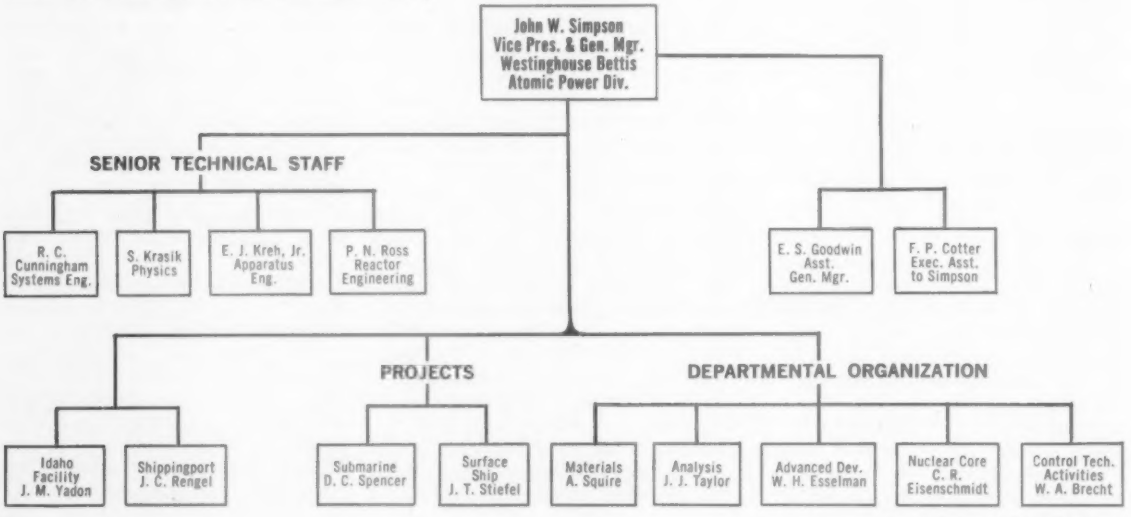
"We have lost from our senior staff only one man in the last six months. . . . As a matter of fact, the losses are lower here than among [engineering organizations] as a whole. . . . I don't really feel a problem today in morale."

The loss of Bettis as it has been would be a major loss to civilian reactor know-how. Bettis personnel have prepared 6,000 documents released through the government's Office of Technical Services, and 2,000 papers presented to scientific meetings or published in the quarterly Bettis Technical Review. Original development work of commercial import has included heat transfer, uranium-oxide, U metals and alloys, zirconium and Zr alloys, irradiation of materials, digital computer codes, reactor instrumentation, corrosion, canned pumps, and others.

Reorganization

Simpson and his associates believe they have many more problems of broad technical implication to solve; the reorganization of Bettis has been conducted along this line. The reactor-by-reactor project approach has been dropped in favor of two over-all projects: submarines and surface ships. In support of these are five departments: materials, analysis, nuclear cores, advanced development and technical activities. Coordinating the entire technical effort are four senior staffers who make up a management

The New Look at Bettis Laboratory



group: Sidney Krasik, physics div.; R. C. Cunningham, systems engineering div.; P. N. Ross, reactor engineering div.; and E. J. Kreh, Jr., apparatus engineering div. [*See chart.*]

In accomplishing the shake-up, Bettis has dropped most production activities in favor of other NRB contractors and sharply reduced its component-purchasing activities in favor of Westinghouse Plant Apparatus Dept., reducing total employment from a high of more than 5,500 a year ago to a low of 4,700 when the reorganization is complete in mid-1959. Major production item at Bettis had been reactor cores; core fabrication is now limited to prototypes.

"I don't look on [the reorganization] as a dramatic thing—it's an evolutionary thing," Simpson explains. "It's a new way of marshalling the troops."

Going further, he sees the reorganization of Bettis as strengthening its potential for technological accomplishment, rather than weakening it. The shifting of production activities to other NRB contractors, for instance, gives the Bettis group the identity of a pure research-and-development organization; the move away from individual reactor projects toward a wider approach to reactor improvement permits of a concentration on technological problems generally.

"Our contribution will be in basic technology," Simpson asserts. "How many megawatt days per ton can you burn uranium-oxide?" What new alloys of plate-type U-oxide fuel elements can be developed to permit a greater heat-transfer surface? How can the technology of heat-transfer be improved?

"We may learn enough so that people can run their reactors safely and wisely, closer to the ultimate limit.

"I feel this is an important contribution. Somebody who just builds the reactor is stopping short of getting the maximum good out of it."

Bettis is expected to do $95-million worth of work for the government this fiscal year, as against $117-million in '58, according to AEC sources.

At KAPL

"We are in the naval nuclear power business almost exclusively," says Caldwell, KAPL's new general manager, a 49-year-old electrical engineer from Austin, Texas, who has been with GE since 1935 and with KAPL since 1954. "With only one significant exception—and that one also a defense item and highly classified—our mission, as set out in the KAPL charter, is to develop, design, and arrange for procurement of hardware for naval reactor power plants, with emphasis on design and development of naval reactors and the components most closely associated with them.

"The shift putting KAPL in the Turbine division had the object of clarifying our life. The Turbine division is in the heavy-equipment business, and ships are a large item of their business, so it seemed a natural grouping. Also their headquarters is here in Schenectady, so for coordination purposes it's better, even though it takes us away from Hanford and the Atomic Power Equipment Department at San Jose.

"But as we go along, our areas of work have less in common with Hanford and APED, even though they are basically alike; our application is somewhat different from theirs, and we are getting more product-oriented."

A stocky, craggy-faced, gray-haired man of 49, Caldwell speaks slowly and so softly he almost seems to be whispering. He is severe in mien, but even his junior associates call him "Tex."

He now has a total of 2,000 under him in KAPL proper, of whom 600–700 are classed as scientists and engineers. The lab has been within 100 of the total figure for several years, and Caldwell expects to stay at the same level for the next several. However he points out that the nature of the work is changing, and so a change in the personnel may be expected also:

"We really have our third complete powerplant to engineer now—the first destroyer, following upon *Seawolf* and *Triton*, and this is paralleled by even more water-cooled plants at Bettis. Consequently a smaller effort is required on reactor components—heat exchangers, engine-room equipment, and so on—with each successive plant, and so we will be going more into reactor and specifically core work, and will do less on general powerplant engineering."

Caldwell's 1959 research-and-development budget is about $37-million, including salaries and the purchase of services from other labs, but excluding costs of prototype construction and of fissionable materials.

KAPL Organization

KAPL is set up on the project system of organization; but since it has but two, and since they happen to be a submarine (*Triton*) and a surface ship (D1G, the first nuclear destroyer), the effect is that the KAPL organization is much like that newly established at Bettis. The two major groups have about 400 people in each, and are each composed of four main subgroups: a reactor engineering component, a powerplant engineering component, a materials development component, and production engineering.

The first includes reactor physicists, heat-transfer specialists, stress analysts and designers; the second does systems engineering for the complete plant, although KAPL concentrates on the reactor compartment—the steam-raising plant; it also draws specifications for pieces of equipment that are then all put out on competitive bid. The third team includes the metallurgists who develop materials, primarily for the core; the fourth includes people who follow construction and testing on the land-based prototype and subsequently on the ship.

Some technical services are not split up and put into the projects, but are kept in a central service group called Technical Operations: these are a metallurgy lab, a chemistry lab, an engineering test facility operated in the interest of both projects, a radiation materials lab that conducts irradiation tests and examines and evaluates the results.

Nucleate Boiling in Next Naval Reactor

The biggest immediate job ahead of the reorganized group at Bettis is development of the naval program's next reactor—a natural circulation, pressurized-water plant with nucleate boiling. The reactor is in design now. The prototype had been scheduled for a construction start in the fiscal year beginning July 1 but a year's delay was decided upon to permit further research and development work. However, according to government sources, construction is definitely scheduled to start in fiscal '61. Some 15–20 other reactor concepts are in a much less advanced stage of study at Bettis.

BERKELEY: No. 1 reactor showing five of the eight boilers grouped around the reactor; all eight are now erected. The two-reactor station is nearly half way to completion after two years' work

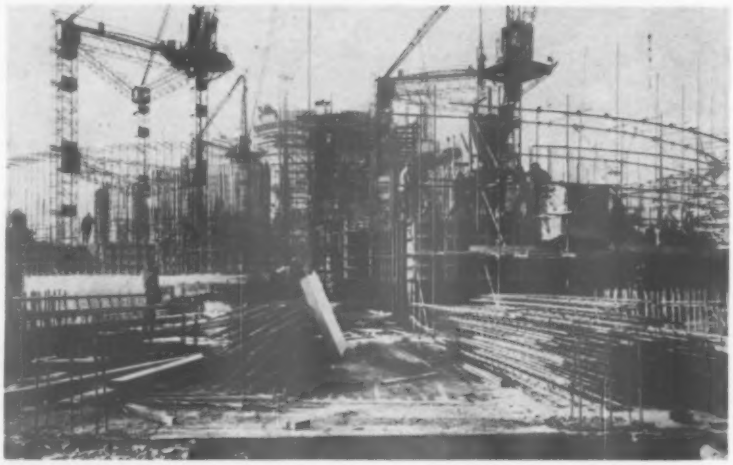
BRADWELL: General view showing No. 1 reactor in left background as shielding walls of No. 2 unit rise (center and behind crane at right). Bradwell and Berkeley are racing to be first in operation

British First-Round Civil Stations Changing Landscape

Britain's first civil power plants, the four two-reactor stations at Bradwell, Berkeley, Hunterston and Hinkley Point, are passing through the period of most visible, most spectacular progress (*compare photos NU, Sept. '58, 77; also report June '58, 23*).

These photos were all taken in February, by the builders: A.E.I.–John Thompson Nuclear Energy Co. Ltd. at Berkeley, Nuclear Power Plant Co. Ltd. at Bradwell, General Electric Co. Ltd. at Hunterston.

Earlier estimates given NUCLEONICS by the Central Electricity Generating Board for start of full-power operation were: Berkeley—No. 1 reactor, Dec. 1960; No. 2 reactor, July 1961; Bradwell—Dec. 1960 and June 1961; Hunterston—Aug. 1961 and Sept. 1962; Hinkley Point—March 1962 and Dec. 1962.



HUNTERSTON: Concrete shielding of No. 1 reactor (center background) rising high above Firth of Clyde is dwarfed in this photo by walls of No. 2 reactor beginning to rise above foundation raft. Hunterston is on a schedule running about nine months behind Berkeley and Bradwell

HUNTERSTON: Radiographic weld-inspection in progress on the bottom crown of the No. 1 reactor pressure vessel. Three-in. thickness of plate can be seen in cross section at arrow (bottom right-center)

HUNTERSTON: The standpipe sleeves being placed in position before casting bottom biological shield of No. 1 reactor. (Spherical Hunterston reactors will be charged and discharged from underneath)

Administration Splits On Prompt Ship Program

The U. S. Maritime Administrator declined to follow the lead of his superior and took a strong stand in favor of enactment this year of authorizing legislation for a nuclear tanker and for a Nuclear Ship Co-operative Program (*see editorial page 85*). In hearings before the House Merchant Marine Committee Feb. 19, Clarence G. Morse, chairman of the Maritime Board and head of the Maritime Administration, urged that there be no further delay in getting these projects under way. The previous day, John J. Allen, Undersecretary of Commerce for Transportation, had told the committee that the Administration would not seek this authorization at this session and clearly implied that if such legislation originated in Congress it would be opposed by the Administration.

Speaking of the interest in a vigorous nuclear merchant ship program displayed by U. S. merchant marine and nucleonics industrialists, Morse said, "They are in full agreement that we cannot pioneer with one reactor type in one passenger-cargo vessel. The *Savannah* will enable us to solve many practical problems and pave the way for general acceptance of nuclear shipping; it cannot answer the specific economic questions raised by builders and operators of tankers, ore carriers, large passenger ships. What we now must do is get on with the construction of a ship which probes the economics of nuclear propulsion. This is something that continued research and development cannot do."

In a move indicative of bipartisan support in Congress for atomic ships, an authorizing bill was introduced later by Rep. Thor C. Tollefson (R-Wash.); Chairman Bonner (D-N. C.) was expected to follow suit. However top-level Administration apathy left the issue in doubt.

On the Nuclear Waterfront

Other developments last month:

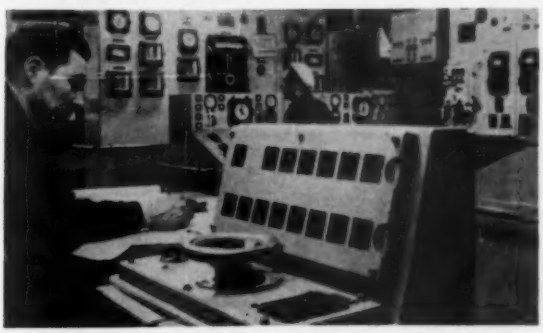
• *Skipjack*, the Navy's super-fast submarine embodying the first marriage of nuclear power to the *Albacore*-type tear-drop hull, went to sea on her builder's trials March 8, sixth nuclear submarine to do so.

• N.S. *Savannah's* main propulsion machinery was completed at the Trenton, N. J., shops of the DeLaval Steam Turbine Co.; put through its paces in several days of testing; obtained the approval of the American Bureau of Shipping, and delivered to the New York Shipbuilding Co. at Trenton, N. J., for installation in the fast-rising hull. Meanwhile Babcock & Wilcox reported that the main heat exchangers had already been shipped and that the reactor vessel and pressurizer are scheduled to be shipped from Barberton, Ohio, in April.

• The Navy assigned six nuclear submarines to shipyards for construction. Two will be built at New York Shipbuilding Co. for a total of $45,389,098, and two at Ingalls Shipbuilding Co. for $49,178,142; these are fixed-price contracts. A fifth goes to Mare Island and a sixth to Portsmouth naval shipyard. All six are attack submarines of the *Thresher* (improved *Skipjack*) type.

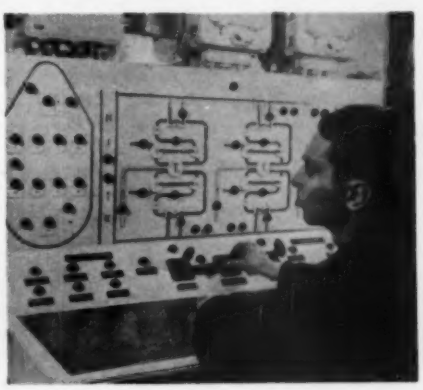
Fitting Out of Russian Nuclear Icebreaker Nearing Completion

LENIN IN FITTING-OUT DOCK in Leningrad. NUCLEONICS' Moscow correspondent cabled that "trials are still proceeding as dockside outfitting nears completion. Initial voyage is expected soon but date is still unannounced. . . .



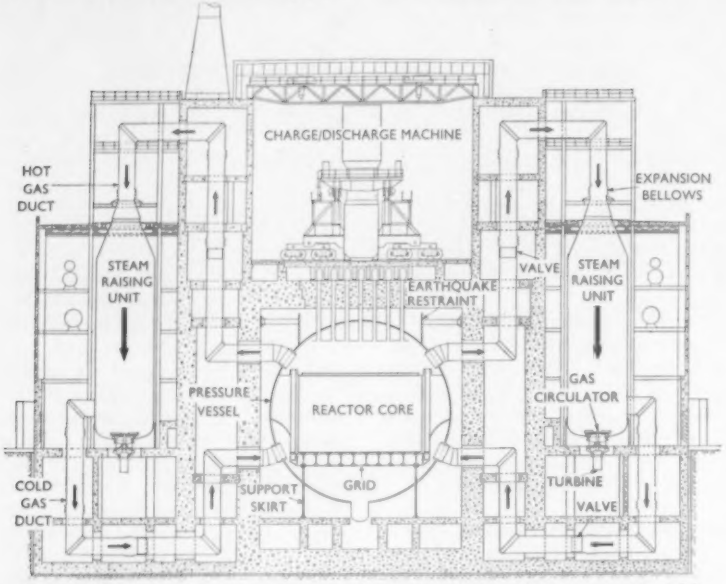
"CONTROL SECTION for steam generation and engines reportedly operating smoothly," Moscow cable continues. "Recently completed: telephone system, galley, helicopter hangar. Carpenters still outfitting interior. . . . "

STEAM GENERATORS in the reactor compartment are shown here (vertical cylinders), with steam lines in foreground



DOSIMETRIST at his post, monitoring radiation. "The crew has been chosen, is ready to take over from the builders," Moscow bureau reports

First Big Japanese Power Plant Order Going to Britain; GEC–Simon Carves Hopes to Start Work This Summer



GEC DESIGN for Japan: compare Hunterston design, NU, May '58, 108.

Britain's General Electric Co.–Simon Carves Atomic Energy Group has won "first candidacy" to build Japan's first large nuclear power plant. Japan has been almost three years making the decision since former Japanese AEC chairman Matsutaro Shoriki announced the order would go to a U.K. firm (NU, July '56, R5).

But nothing is settled yet; sale is subject to negotiations expected to drag into the summer. GEC was low bidder at $50-million, but this was more than the Japan Atomic Power Co. (NU, May '58, 24) expected since GEC had bid $45-million on the SENN job last year. Now JAPCO is asking GEC to come down in price.

[Later, the U. S.'s General Electric (no connection) was picked to supply a small demonstration power reactor for JAERI. The $~8.6-million, 12.5-Mw(e) boiling-water unit, slated for 1962 operation, will be built in part by Tokyo Shibaura Electric Co. and Hitachi Ltd.]

If contract negotiations are successful, the 159-Mw(e) advanced gas-cooled Calder-type reactor will be built at the Japan Atomic Energy Research Institute (JAERI) at Tokai, about 70 mi NE of Tokyo. Construction would begin this summer, and the reactor is to be completed by the fall of 1963. Total budget for the station including civil engineering, to be done by Japanese firms, is $84-million. Construction contractor will be FAPIG—the First Atomic Power Industry Group.

Although GEC's price did not satisfy JAPCO, its "progressive improvements" beat the leading rival, English Electric Co. GEC's newly-designed annular fuel elements, more economical and with increased heat-transfer surfaces; its charge and discharge devices and its earthquake-proof features were deemed better. Also the 159-Mw output is 9 Mw better than JAPCO specified. Loading is 180 tons of natural uranium over a five-year period.

The reactor is an improved version of the twin reactors GEC–Simon Carves is building at Hunterston near Glasgow in the first round of British civil nuclear power stations. Major changes from Hunterston specifications have been incorporated to meet earthquake contingencies. These include:

- Overhead charging and discharging facilities, lowering the center of gravity of the entire structure above ground by 40 ft;
- Reactor vessel and heat exchanges are mounted on a substantial continuous reinforced concrete raft, considered the primary safeguard against differential displacement between these elements that would rupture coolant circuits;
- Control system so divided that small clusters of control rods can be moved independently in the event of small local core displacements;
- An emergency scram device incorporated that remains effective for a core tilt up to 45 degrees.

Current negotiations revolve around these questions: will GEC lower its price? how will GEC actually guarantee 3,000-Mwd burnup? how long will the payment period be (the British are asking seven years against Japan's ten)?

Next Question on SDR: Build an Experiment?

Hard on the heels of the indefinite postponement of the sodium-deuterium reactor project of Chugach Electric Cooperative/Nuclear Development Corp. of America, AEC has organized a nine-man task force* to judge the concept's technical and economic potential.

In this order: Chugach's SDR has been dropped for the foreseeable future; a decision has been made to look at the possibility of building an SDR experiment at an AEC site; and the new task force has been asked to make the preliminary decision on an experiment. If the group's recommendation is favorable on an experiment, a final decision is expected from AEC in May or June. If it is unfavorable, the Commission is expected to discuss a different reactor concept with Chugach.

"This review will be based upon present technology as developed by NDA," explained an AEC official. "Only present technology is to be considered."

* E. D. Jordan, and J. J. King of AEC's Reactor Development div., co-chairmen, F. A. Smith and D. H. Lennox, Argonne National Laboratory; J. W. Wade and J. P. Maloney, Savannah River installation; J. A. Weir, Oak Ridge National Laboratory; T. V. Kavanagh, Gibbs and Hill; and L. E. Link of Argonne, consultant.

3 Reactors for Antarctic Planned, Says Adm. Dufek

The Navy's head man in the Antarctic, Rear Admiral George Dufek, disclosed last month that power-and-heat reactors are planned for three bases there within three years —McMurdo Sound, South Pole and Cape Ahllett. His disclosure was made at a press conference in Canberra, Australia. Navy spokesmen in Washington confirmed that reactors were under consideration in the Antarctic, but said no concrete action has yet been scheduled to get the necessary funds from Congress.

Reactor News

BURLINGTON MAKES PROPOSAL TO AEC

The city of Burlington, Vt., came in to AEC with a formal proposal regarding the OMFBR or organic-moderated fluidized-bed reactor it is working on with Westinghouse (NU, Sept. '58, 153; Nov., 24). AEC was asked to finance a $580,000 first-phase research-development program toward a 30–50 Mw(e) power plant, and to earmark a total of $8.5-million for the entire research program if the first phase confirms the concept's promise.

SECOND-GENERATION FERMI STUDIED

Preliminary review of an improved fast reactor has revealed a number of improvements that could be made in the 100-Mw(e) Enrico Fermi Fast Breeder were it being designed today (*see p. 131*). This proved so encouraging that Atomic Power Development Associates (APDA), Detroit Edison, Allis-Chalmers, Babcock & Wilcox, United Engineers & Constructors Inc. and Commonwealth Associates have set up a 35-man group to make an intensive preliminary design of a second-generation fast-breeder power plant. A report was due April 1, with the object of showing the status of advanced fast reactors and the development cost, program and schedules required to reach economic power via the Pu-fueled fast reactor route.

ANOTHER CONCEPT: THE PASTE REACTOR

APDA has also been working on a "paste reactor" concept. Feeling that the best advanced fast breeder will have mobile fuel, it has been investigating the properties of a fuel mixture of a thick paste of uranium-molybdenum alloy in sodium, moving very slowly through a core of 19 subassemblies each containing 100 tubes. On the return leg outside the core, additional sodium would be added to permit freer flow; it would be separated by hydroclone before the paste re-entered the core. The paste, with a consistency like wet mud, can be pumped, it's already been shown, and paste capsules are being irradiated at Battelle to check on fission-product-gas release (a major problem is that if such gas formed large bubbles, it might cause instabilities).

AEC APPROVES NEW PIQUA SITE

Subject to provision of additional containment, AEC has approved the new site proposed for the Piqua, Ohio, organic-moderated nuclear power plant (NU, Dec. '58, 25; Jan. '59, 24). The AEC action came after the Advisory Committee on Reactor Safeguards approved the new site provided a "more substantial and dependable" containment system is included.

TREAT GOES CRITICAL IN IDAHO

The Transient Reactor Test Facility (TREAT), a $1-million reactor built just to produce short, extreme pulses of nuclear energy and thereby high temperatures, went critical Feb. 23, to become the 18th operable reactor at the National Reactor Testing Station in Idaho. The surges will simulate abnormal reactor operating conditions and the extreme heat generated will permit meltdown studies on samples of fuel elements and components intended for use in fast reactors placed on the axis of TREAT's annular core. TREAT's transient pulses are believed to be of greater intensity—3×10^{19} n/cm²/sec peak flux for 50-millisec bursts, 3×10^{18} integrated flux per burst—than can be safely attained in any other reactor. For safety, the control room is housed half a mile away. TREAT will also serve as a versatile irradiation tool for study of other fast-reactor safety problems. Early studies will test behavior of prototype fuel pins for the Experimental Breeder Reactor No. 2; later, metal-water reaction experiments are also planned. TREAT went critical on 146 fuel elements containing 5.38 kg U^{235}; for flexibility of experimental arrangements, space is provided for loading up to 361 elements. These are 9 ft long, with upper and lower graphite moderator sections canned in aluminum and a 4-ft central section of uranium oxide uniformly dispersed in graphite, fabricated as six 8-in. fuel blocks canned as a unit in zircaloy. The $7 \times 7 \times 14$-ft-high reactor cavity is lined with graphite reflector made of blocks that had served in Enrico Fermi's original Chicago Piles 1 and 2. Argonne designed the facility.

FURTHER DEVELOPMENT FOR APPR . . .

The Army Package Power Plant, already pushed up from 10 Mw(th) in the first version at Ft. Belvoir, Va., to 20 Mw(th) in the second at Ft. Greely, Alaska, will be boosted to 28 from the same size core under a new $2-million development job Alco has been working on for the Army. This APPR-1-b is intended for "remote defensive installations" for the Nike missile family.

. . . AND A NEW MOBILE PLANT STUDY

Clark Bros. Co. of Olean, N. Y. is doing a feasibility study for the Army on a transportable 750-kw(e), open-cycle air turbine plant with a sodium-cooled reactor.

AEC SIGNS FOR FLORIDA PLANT

The East Central Nuclear Group and the Florida West Coast Nuclear Group have signed with AEC for research and development work on their heavy-water-moderated, gas-cooled plant to be built on Florida's west coast. The contract represents fruition of a proposal made and approved in principle by AEC a year ago (NU, Jan. '58, 17; Mar. '58, 17). ECNG will carry out an $18-million research program on the pressure-tube reactor, with AEC paying up to a maximum of $13,180,000 (including waiver of use charges). FWCNG will assume the $26-million construction costs and will operate the plant on the grids of its two component companies, Florida Power Corp. of St. Petersburg and Tampa Electric Co. FWCNG will also pay excess operating costs over those of a conventional plant, put at $5.4-million for the first five years of operation of the 50-Mw(e) plant. AEC announced that "prior to start of construction, a determination of technical and economic feasibility will be made"; FWCNG may elect to drop the plan if the cost of power is estimated to be more than 50% higher than conventional power in the area, or if the reactor is held technically unfeasible. General Nuclear Engineering Corp., now a subsidiary of Combustion Engineering (NU, Feb. '59, 22), continues its role in the project as nuclear design agent; American Electric Power Service Corp. is expected to be principal design and construction engineer.

PWR SPENDING HIT; OTHER LATE NEWS

Weaknesses in the application of administrative controls were blamed, in a General Accounting Office report to Congress, for the increase in the total cost (including research-development) of Shippingport from $90,750,000 in May, 1954, to $119,340,000 in December 1957. . . . Brookhaven's medical research reactor, first reactor designed exclusively for medical use, went critical March 15 . . . Minnesota Mining & Manufacturing has joined Republic Aviation and Allis-Chalmers as third sponsor of a proposal to AEC to build a 100-Mw test reactor (NU, March '59, 24).

ROUNDUP

World News

SELNI on U. S. Deferred Payment Plan

Italy's SELNI nuclear power project has become the first project to be approved under AEC's deferred-payment plan for enriched fuel (NU, March '59, 28). SELNI, in which Edisonvolta of Milan, Italy's largest utility, plays a leading role, has a contract with Westinghouse for a Yankee-type 134-Mw(e) reactor. Two sites are under consideration, one of them understood to be on Lake Como. SELNI hopes to break ground this spring; first fuel is to be delivered by the U. S. in 1961. U. S. aid is being extended under the bilateral with Italy, not under the joint U. S.-Euratom program.

British Competitor for Argonaut: Jason

Hawker Siddeley Nuclear Power Co. is building a 10-kw research reactor based on the Argonaut design; with proper deference for mythology it is being called Jason. The first unit will be completed in September at Hawker Siddeley's Langley works in Buckinghamshire. HS hopes to sell Jasons to universities, hospitals and other research centers, in Britain and abroad.

U. K. Gearing for Beryllium Production

Imperial Smelting Corp. will start first British commercial production of reactor-grade beryllium metal at its zinc plant at Avonmouth, Gloucestershire. The plant is due to begin production by year's end; the AEA will be the major customer. The project is in two stages, with the second depending on the success of the first. The firm declines to tell plant output; U. K. demand for beryllium is estimated at 100 tons/yr by 1965, for fuel cladding for second-stage civil power reactors. Imperial Chemical Industries Ltd. is also building a plant—also due for completion by year's end—to produce semi-fabricated beryllium.

2 Euratom Countries to Collaborate on Plant

Electricité de France has formally agreed with Belgium that the "Centrale des Ardennes"—the nuclear power plant it is planning to build in the Ardennes forest near Givet close to the Belgian border (NU, July '58, 26) will be built and operated in collaboration with Belgium.

Nuclear Power for British Guiana?

The Mitchell Engineering Group Ltd. of London is negotiating with the government of British Guiana to build an $11-million, 20-Mw(e) nuclear power plant to increase the South American colony's power supply.

British Briefs

The first of the four Chapel Cross reactors, which went critical in November (NU, Dec. '58, 26), began feeding power into the national grid Feb. 25. The other three reactors at Chapel Cross—Britain's second power-producing nuclear installation and first in Scotland—are to follow at three-month intervals. The station will be officially opened May 2. . . . Britain will get the advanced S5W or *Skipjack*-type reactor for her first nuclear submarine *Dreadnought*, the First Lord of the Admiralty, announced. There had reportedly been some disagreement over whether Westinghouse would supply the original S5W plant or an improved version (NU, Aug. '58, 19; March '59, 19). *Dreadnought*'s keel will be laid by Vickers this summer. . . . Sir William Penney, Atomic Energy Authority member for weapons and builder of Britain's first nuclear bombs, will become member for research when Sir John Cockcroft becomes master of Churchill College, Oxford. Nyman Levin has been promoted from deputy to director of the Authority's weapons group, taking over from Sir William who had been combining the jobs of director and Authority member for weapons.

Ippolito Heads Euratom Supply Advisers

Felice Ippolito, secretary general of Italy's CNRN (National Committee for Nuclear Research) has been named president of the 24-man Advisory Committee of Euratom's Supply Agency. The committee will help the Agency control its relations with consumers of nuclear fuel. The Supply Agency starts functioning April 1.

First Pure U Production in India Begun

A new $462,000 plant built near Bombay at the Trombay center of India's Department of Atomic Energy has produced Asia's first nuclearly-pure uranium; the first ton was produced at end of January (NU, July '57, 27). Raw material for the plant is monazite sands from Travancore (south India) coasts containing up to 0.28% U_3O_8, after thorium and rare earths have been separated out in two plants of Indian Rare Earths (Private) Ltd. at Alwaye and at Trombay (NU, Feb. '56, 15). However the plant can also treat other concentrates like sodium diuranate, uranium oxide concentrates, etc. Designed as a pilot plant, its output can be expanded sufficiently to produce replacement U metal for a 250-Mw(e) natural-U reactor. First job for the new plant: to make the U to fuel the Canada-India reactor and the Zerlina critical facility both now nearing completion. Equipment for the plant was built by Degussa of Frankfurt.

Italian Items

Italy's nuclear-risk insurance pool, comprising 62 Italian firms and 25 foreign participants, issued its first policy, covering the subcritical experimental reactor at the University of Cagliari, Sardinia. It covers fire, lightning, explosion, excessive temperature, contamination of the insured and decontamination costs, third party liability for contamination of persons and objects. . . . The first shipment of U. S. enriched fuel to Italy has arrived at Ispra, for Italy's CP-5 type research reactor nearing completion; the 32 fuel elements, made by Babcock & Wilcox and containing 48.5 lb U, are worth $150,000.

Nuclear Lab for Britain's CEGB

The Central Electricity Generating Board is planning a $2.8-million research center adjacent to, but divorced from, the Berkeley nuclear power station, to study power reactors and intensely radioactive materials.

American–European Fuel Contacts

Union Minière of Belgium has made its first deliveries of high-purity uranium orange oxide to AEC. Mined at Shinkolobwe in Belgian Congo, it was refined at a new plant at Olen near Antwerp. . . . Degussa in West Germany becomes European sales agent for Mallinckrodt uranium products under an agreement for technical collaboration.

Spain Joins Eurochemic Project

The OEEC Council has approved Spain's participation in the 12-nation project to build a jointly-owned chemical reprocessing plant at Mol, Belgium.

News in Brief

AEC Lays Major Accident Blame on Victim

" . . . the accident was directly attributable to errors on the part of the deceased operator . . . " This was the major conclusion of AEC's Investigation Review Committee on the Dec. 30, 1958, accident at Los Alamos which brought death to Cecil W. Kelley (NU, Feb. '59, 21). However, the Committee also suggested that Kelley had too much autonomy even though "normal procedures" were being used in his transfer of plutonium and organic solutions between containers in a chemical Pu recovery process. The Committee urged "closer supervision" at Los Alamos and wide dissemination of the facts of the case for educational purposes. (*Details p. 107*)

AEC Reorganizes Sherwood Steering Committee

The advisory committee to AEC on controlled fusion—Sherwood Steering Committee—has been reorganized and enlarged. The reshuffling took place, according to AEC officials, because "the project has grown very big" and it was felt that "we could do business a little better." A major change was the dropping of people who have direct project responsibility—for example, Lyman Spitzer, Jr., of Princeton and James L. Tuck of Los Alamos—in favor of "outside" advisers—Subrahmanyan Chandrasekhar, Univ. of Chicago, William A. Fowler, Cal Tech; and Robert R. Wilson, Cornell Univ. Other new members are: Norris E. Bradbury, director of Los Alamos; Henry D. Smyth, Princeton; Edward Teller, director of Lawrence Radiation Laboratory; and Alvin M. Weinberg, director of Oak Ridge National Laboratory. The committee is chaired by John H. Williams, director, AEC's Research Div.; secretary is Arthur E. Ruark, chief of the controlled thermonuclear branch.

Krypton-85 Output Raised Five-Fold at ORNL . . .

AEC's Oak Ridge National Laboratory has increased the supply of krypton-85 available for civilian uses from 20,000 curies/yr to 100,000—"in response to industrial requests." The radioisotope, AEC said, "is finding increasing use for activating phosphors in self-luminous light sources." AEC's price remains unchanged: $50 for each of first two curies, $15 each additional curie.

. . . As Radioisotope Shipments Climb . . .

The figure 37 was the magic one for ORNL as it reported its biggest year (1958) in the 12½ years it has been shipping radioisotopes to users in the U. S. and abroad. ORNL shipped 228,717 curies—37% greater than the 1957 total and 37% of all shipments since the first on Aug. 2, 1946. Number of shipments increased only slightly between '57 and '58; the growth was in size of individual shipments.

. . . And AEC Reviews Irradiator Bids

AEC is reviewing several "expressions of interest" from industry in its offer to support construction of a high-level irradiator (NU, Jan. '59, 27); it was understood that the industry response did not come up to AEC expectations but that no decision would be made by AEC to go ahead on its own until after further negotiations.

High Voltage Plans Dutch Plant, Has Record Sales

Riding high in its radiation-machine field, High Voltage Engineering Corp. last month reported (1) plans to build a manufacturing plant in Amersfoort, The Netherlands; and (2) record sales and earnings in 1958. Denis M. Robinson, HVEC president, said the Dutch location will permit the company to "participate directly in the economic community" formed by the six Euratom countries, although it will serve all European countries, the Near East and Africa. HVEC reported an 18% gain in sales and a 55% gain in operating earnings for itself and its affiliate—Electronized Chemicals Corp.—during 1958. Earnings were $1.33 per share on sales of $5,786,509; backlog was $6,507,359 on Dec. 31.

Townsend Named N. Y. Atomic Director

After the New York State legislature had rushed through a bill creating an Office of Atomic Development (it passed both Assembly and Senate the same day, three days after being proposed by Gov. Rockefeller), Oliver Townsend was named first director. Former assistant to AEC Chairman Gordon Dean, Townsend, 42, was a principal architect, and since 1954 assistant executive manager of the Atomic Industrial Forum.

AEC Picks 24 Fuel Cycle Projects

Of 111 proposals by 39 firms for 1–3-yr fuel-cycle development projects (NU, Jan. '59, 25), 24—by 18 firms—have been picked by AEC to share in its $25-million aid program. The firms: ACF Industries, American-Standard, Babcock & Wilcox, Battelle (2 projects), Carborundum, Clevite, Combustion Engineering (4), Denver Research Institute, Electro Metallurgical Co., General Electric, National Carbon, NDA (2), Nuclear Materials & Equipment, Nuclear Metals, Olin-Mathieson (2), Sanderson & Porter, Technical Research Group, Westinghouse.

Battelle, Spencer Building Fuel Facilities

A midsummer construction deadline has been set for two new nuclear-fuel facilities: Battelle Memorial Institute is building a lab especially designed for plutonium studies; Spencer Chemical has started construction, at its Jayhawk Works near Pittsburg, Kan., of a uranium-oxide production plant of 50 tons/yr capacity. Battelle will center its lab work on the use of plutonium, its alloys and compounds, as power-station fuel. Spencer says its new plant will establish the firm as "a major processor of uranium oxide," using a continuous process.

Victoreen Sets Up Two New Divisions

Creation of two new divisions—industrial automation and infrared—has been announced by Victoreen Instrument Co. Clive M. Yeomans, as head of the industrial automation div., will focus Victoreen's development of radioisotope applications in process control, nondestructive testing, gamma irradiation and polymerization.

ASA Official Chides Nucleonics Industry

Cyril Ainsworth, deputy managing director of the American Standards Assn., took to task the nucleonics industry last month for an alleged lack of financial support of ASA's nuclear standard program. He declared: "The . . . program initiated under ASA procedures costs about $25,000 a year to administer. This is small change compared to the multimillion dollar investments needed to develop nuclear power. Yet it is difficult, or almost impossible, to collect this amount fully."

NSEC, Goodyear Get AEC Isotope Contracts

Major contracts under AEC's Isotope Development Program have been awarded to Nuclear Science and Engineering Co. and Goodyear Tire & Rubber. NSEC's, for $133,000, covers three phases of research on adapting isotopic techniques to hormone and pharmaceutical work. Goodyear's, for $50,000, covers development of an isotopic dating technique for broad industry use.

AEC Seeks $195-Million For '60 Building Program

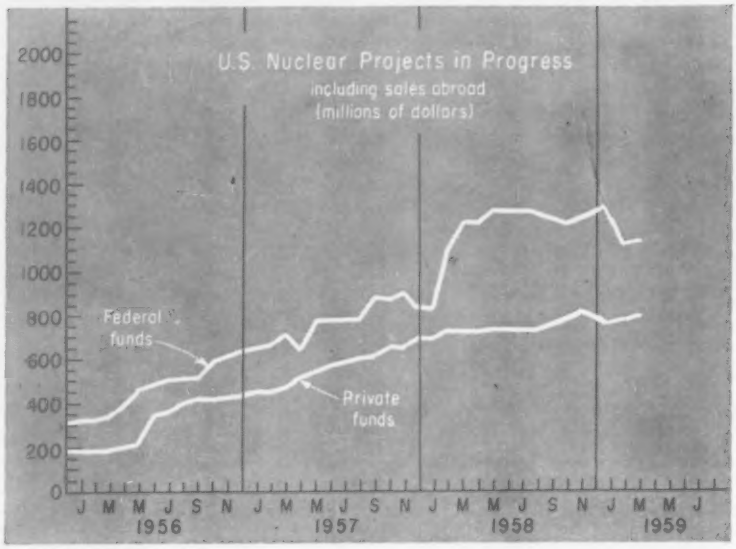
AEC's authorization bill for the upcoming fiscal year proposes $195-million for construction of new projects or modification of existing projects, including the new reactors publicly announced by AEC last month (NU, March '59, 17). The bill also provides $14-million for the U. S.-Euratom research and development program, and drops the $17-million LMFRE (Liquid-Metal Fueled Reactor Experiment) which was to have been built at Brookhaven by Babcock & Wilcox. Other highlights:

• **Cooperative Reactor Program.** There is a net reduction of $20-million. Increases include $1.5-million for lab support work of the Fermi fast breeder reactor; $114,000 for Elk River spare parts; $1.8-million for added costs from Piqua relocation; and $2.5-million for support of the nuclear superheat program of Northern States/Allis-Chalmers. Decreases include $7-million authorized earlier for the defunct Pennsylvania Advanced Reactor project and $20-million authorized last year for possible reactor proposals from industry.

• **AEC's Reactor Program.** A $10-million, high-flux research reactor (2×10^{15} flux) for construction at Brookhaven; a $5-million, pressurized-water test reactor at National Reactor Testing Station for full-scale testing of cores to be installed in military field reactors; $1-million for modification of Experimental Breeder Reactor No. 1 at NRTS, primarily to prepare EBR-1 for a plutonium core and other advanced experiments; $2.5-million for an undetermined number of hot cells costing $300–800,000 each to be built at AEC laboratories; $2-million for modification of the Materials Testing and Engineering Test Reactors at NRTS, primarily to expand service facilities and provide more lab space for experiments going in and out of the reactors.

• **Isotope Development Program.** A $1.6-million, high-level radiation laboratory for research and development on radiation physics and engineering parameters of high-intensity, large-surface-area radiation sources; a $1.5-million process development lab for basic research on use of isotopes in industrial processing activities; and $300,000 expansion and modernization of the radioisotope production area at Oak Ridge National Laboratory.

NUCLEONICS Statistics of the Month



	Latest month	Month ago	Year ago
Nuclear Contracts *—			
Contracts awarded for federal projects ($10³)	8,835	4,145	2,455
Proposed construction, privately-owned ($10³)	0	0	22,500
Contracts awarded, private work ($10³)	0	24,500	0
Backlog of private projects ($10⁶)	260	276	269
Isotope Use †—			
Applications for isotope use	655	706	328
Cumulative total of isotope users	4,847	4,568	3,512
ORNL shipments (curies)	3,904	5,893	1,162
Public and private export shipments	107	377	252
Employment †—			
AEC employment	6,687	6,790	6,787
Construction and design contractors' employment	10,167	11,039	10,181
Total operating contractors' employment	103,908	103,702	100,067
Production workers	51,839	51,263	50,299
Research and development employees	46,282	46,642	43,651
Miscellaneous workers	5,789	5,797	6,117

U. S.-built Reactors ‡—

	Operating	Building	Contracted
Power, domestic	1	7	6
Power, for export	0	1	3
Power experiments and pilot plants	7	4	1
Military and naval	8	20	16
Research and test, domestic	57	20	49
Research and test, for export	11	13	10
Total	84	65	85

Foreign-built Reactors ‡—

Power, domestic	8	25	8
Power, for export	0	1	1
Research and test, domestic	28	15	9
Research and test, for export	6	6	1
Total	42	47	19

* From *Construction Daily*, a McGraw-Hill periodical † From AEC ‡ NUCLEONICS figures

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c) 10309: Long Thin Wall Counter

d) 10310: Civil Defense Counter

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RCL Halogen Quenched Counters — Non-metallic cathode — No hystersis — "Student Proof" — 100% Gas Efficiency

Name	Model Number	Dia. & Lgth. (Dimensions in Inches)	Active Anode Length Inches	Nominal Starting Volts	Typical Plateau Length Volts	Average Plateau Slope Percent/100 Volts	Window or Wall Thickness mg/cm²	Connection
Mica Window Halogen	10104	1-5/8 x 4	1	1000	250	1-2	1.4 or less	4 prong
	10105	1-5/8 x 4	1	1000	250	1-2	1.5 - 2.0	4 prong
	10106	1-5/8 x 4	1	1000	250	1-2	2.1 - 4.0	4 prong
General Purpose, Thin Wall Counter	10308	1-1/8 x 6	3-1/8	900	200	2	30	4 prong
Long Thin Wall Counter	10309	1-1/8 x 10	7-1/8	900	200	1	30	4 prong
Civil Defense Counter	10310	9/16 x 3-1/4	3/4	800	150	2	30	3 prong
Thin Wall Counter for Survey Meters	10311	5/8 x 4-3/4	2-3/4	800	150	2	30	3 prong

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Atomfair April 5–10

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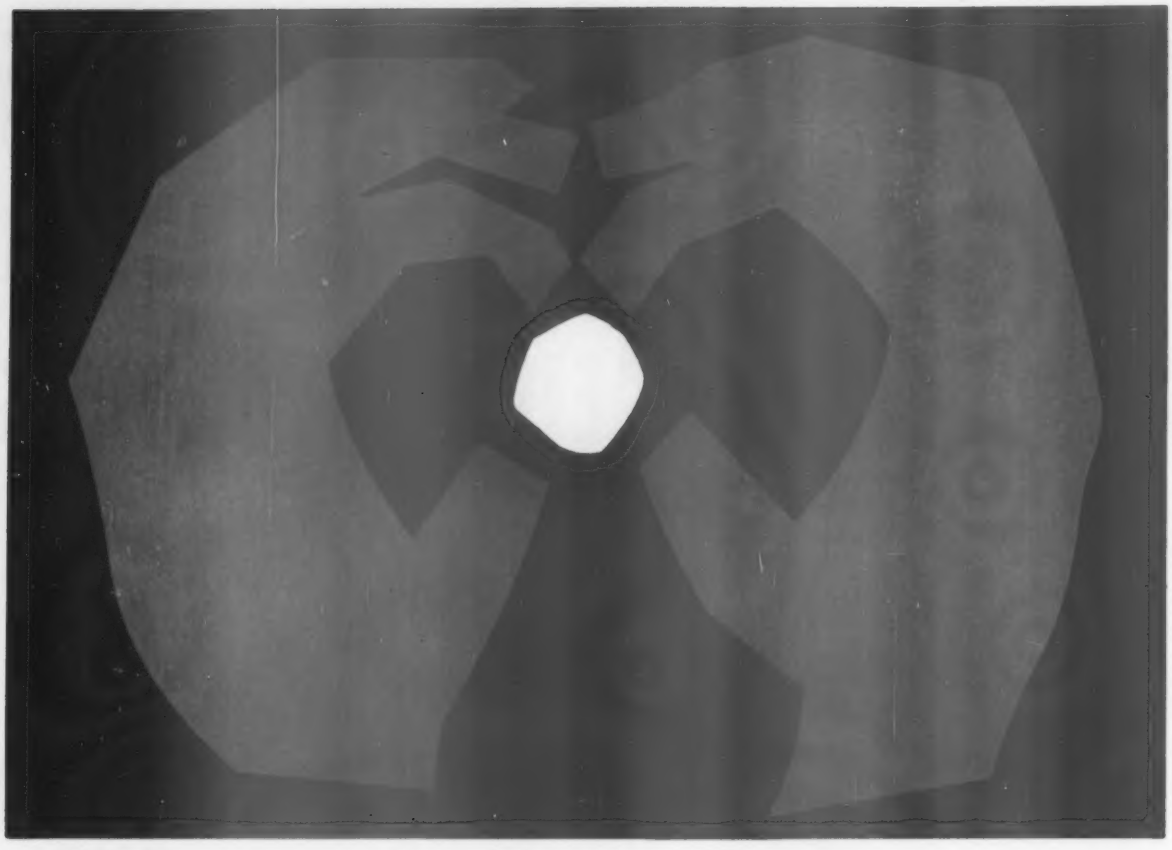
See a demonstration of RCL's halogen quenched Geiger counters and RCL's new family of transistorized nuclear instruments and multi-channel analyzers.



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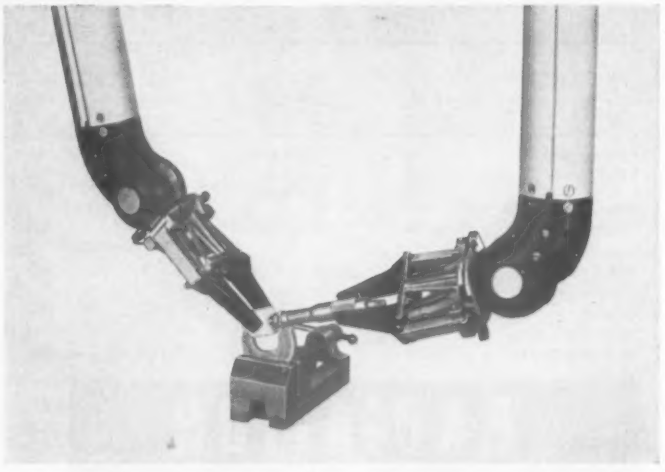
Central Research Laboratories will be glad to advise you on the handling of radioactive materials, explosives, hazardous chemicals, biological materials—in the layout of hot cells—in other research areas, too. For complete information, write CRL today.



Central Research Manipulators from basic Argonne National Laboratory design

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Red Wing, Minnesota, Dept. 101

Safe/Scram

A LOW COST NUCLEAR CORE CONTROL ROD DRIVE FOR POOL TYPE REACTORS

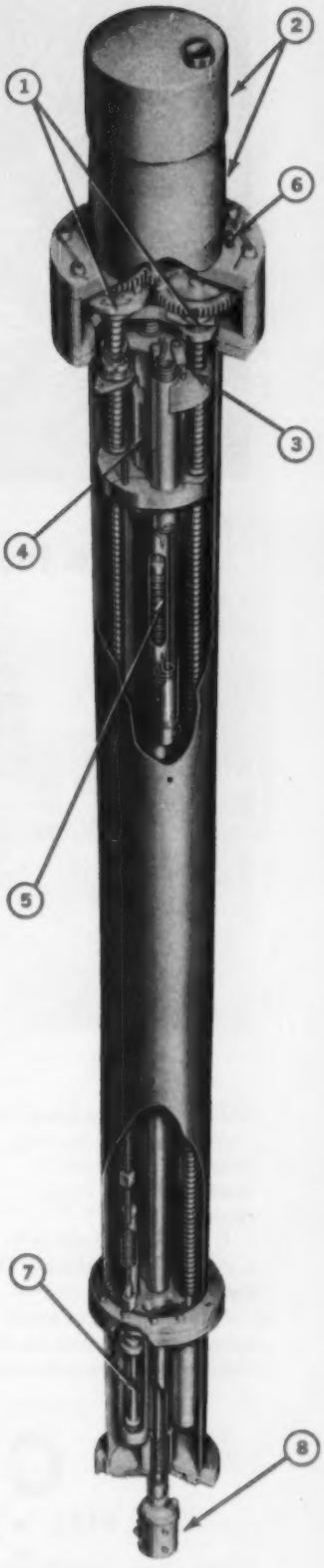
Operators of research and critical pool type reactors will be pleased to know that Vard has designed a new regulating and safety control rod drive mechanism especially for their applications—the Vard "Safescram." Avoiding many complexities of units designed for other types of reactors, the new mechanism is comparatively low in cost. The Vard Safescram is for use where remote control is required, and offers the following features:

1. **Position Indication**—Accurate to ±0.010 inch, dependent on positioning rate. Provides input to digital counter or computer coder.
2. **Drive Motor**—¼ H.P., 3 phase, 60 cycle, 900 RPM induction type with integral brake.
3. **Limit Switches**—Two pairs. Any one of four switches opens circuit, providing 100% motor control safety factor.
4. **Fail-Safe Scram Latch Magnet**—No moving parts.
5. **Scram Spring**—Designed to meet stringent scram time requirements.
6. **Stroke Adjustment**—Settings from zero to full stroke by adjustment of limit switch actuation.
7. **Dash Pot**—Variable-orifice water buffer minimizes forces acting on core, control rod and supporting system.
8. **Control Rod Latch**—Control rod can be released from scram shaft by remote disconnect latch without draining pool or disturbing mechanism. Safety light indicates when control rod latch is fully engaged.

Coasting and Downcreep—Controlled to ±0.0625 inch.

Reversal Time—0.20 second from full "In Positioning Rate" to full "Out Positioning Rate."

The new Vard Safescram offers a low-cost standardized basic design that can be made readily available in modifications to meet specific customer requirements. For more information write for Data File NU-631-1.



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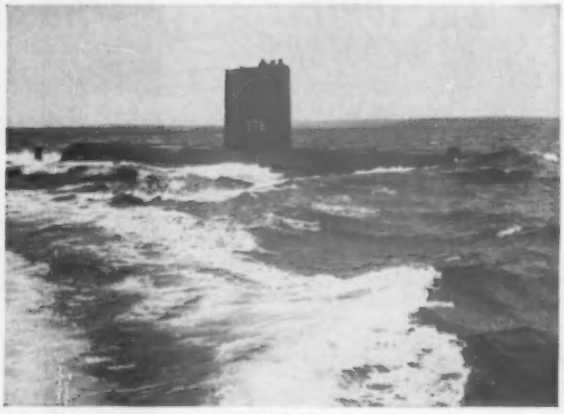

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U. S. S. Longbeach . . . Carrier CVAN-1 . . . Destroyer DDN-1 . . . and more to come!

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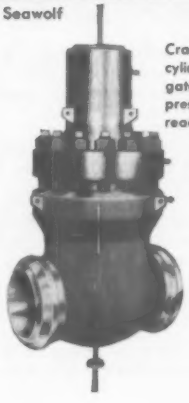
Crane, pioneer in basic research and production of valves for control of radioactive fluids, keeps pace with every new development, every new need, of atomic engineers for installations afloat and ashore.

This is an important fact to remember if you are planning atomic facilities of any kind. Even though your plans are still on the boards, NOW is the time to talk to Crane about valves.



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"IS THERE A WAY," scientists at Spencer Chemical Company asked themselves, "to produce uniformly pure atomic fuel from different kinds of raw material? Is there a way to avoid the generation of scrap in this process? Is there a way we can help the fuel element fabricator gain greater productivity?" Some twelve months ago, Spencer scientists tackled this problem.

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2. **UF_6—Uranium hexafluoride** — a uranium compound supplied by the Atomic Energy Commission.
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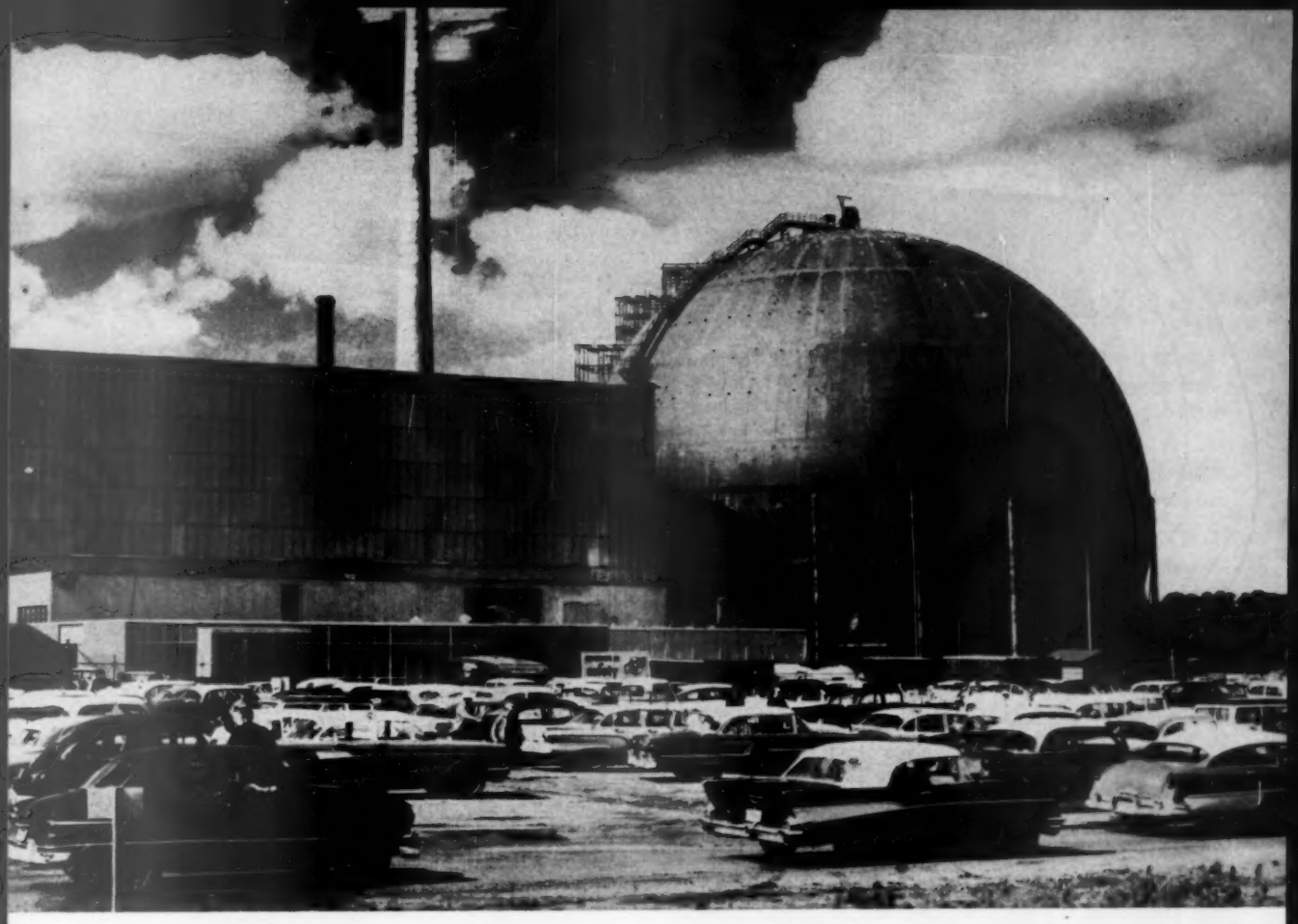
To provide maximum operating efficiency in both the fuel fabrication plant and the nuclear



Process by Spencer

reactor, it is essential that the uranium oxide power have uniform physical properties and extremely high chemical purity. Spencer Uranium Oxide, produced by this recently perfected process, meets both of these rigid requirements.

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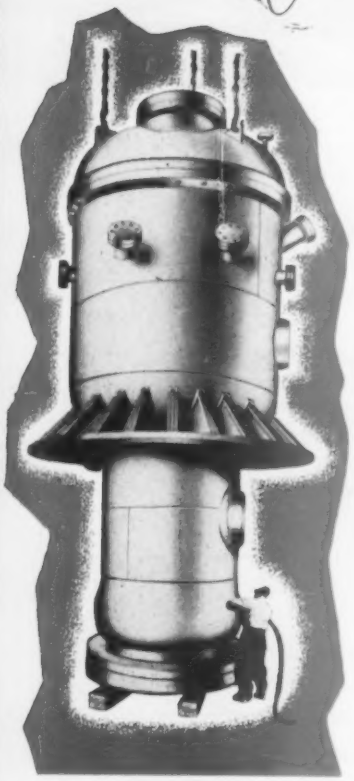
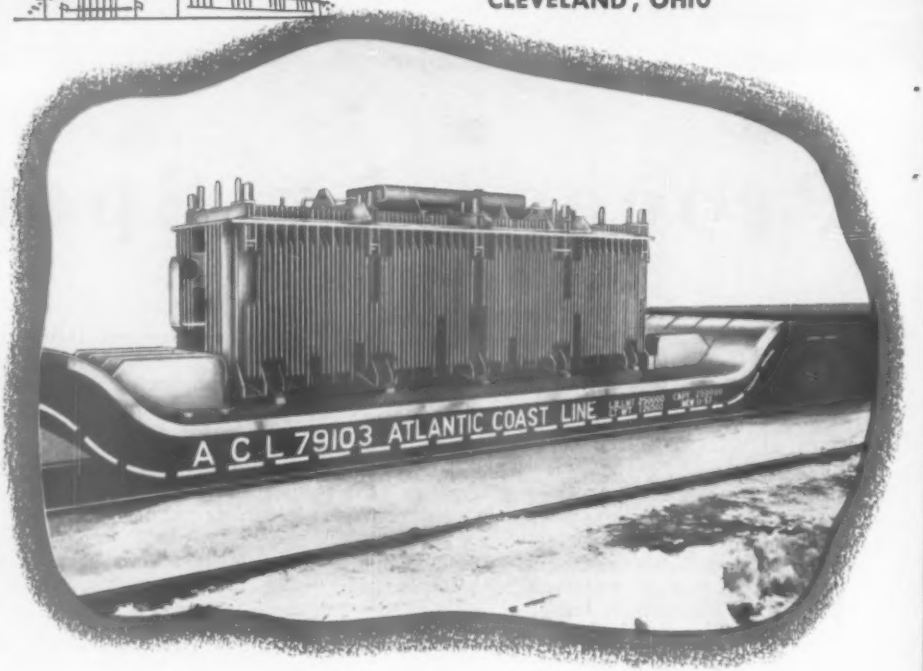
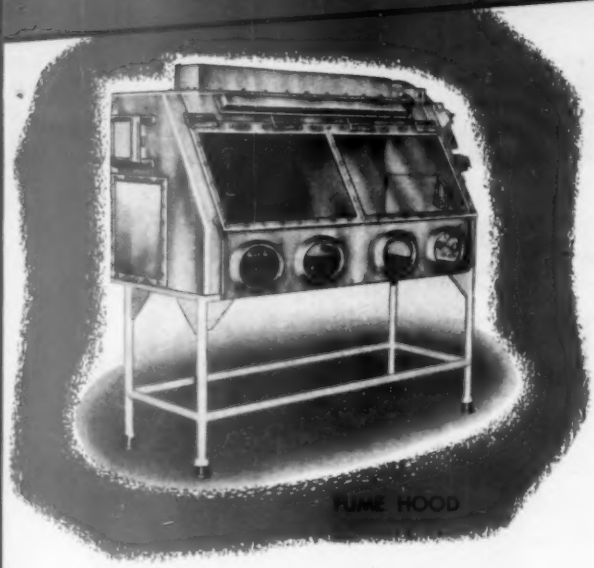


. . . **ETR** recently built by O. G. Kelley & Company for the A. E. C. Installation, Scoville, Idaho



One of a group of lead filled "Transportation Casks" built for E. I. du Pont de Nemours & Company, Savannah River plant, Aiken, South Carolina. These casks, which are used for the shipping of radioactive materials, are fabricated from stainless clad steel with a 8¾" thickness of lead homogeneously bonded to the interior carbon steel surfaces for heat transfer and radiation shielding. The hundreds of stainless steel "fins" on the exterior surfaces permit the dissipation of heat.

Serving the Nuclear Industries



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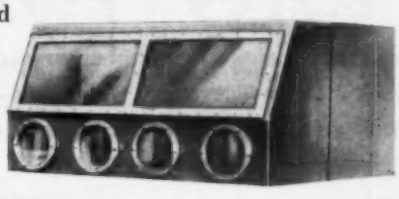

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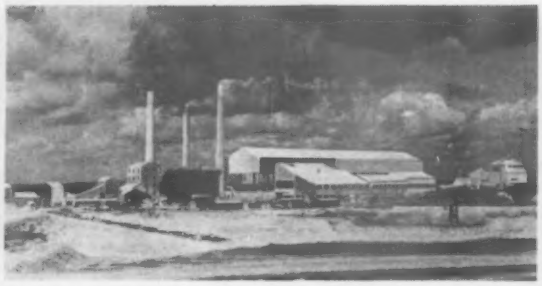

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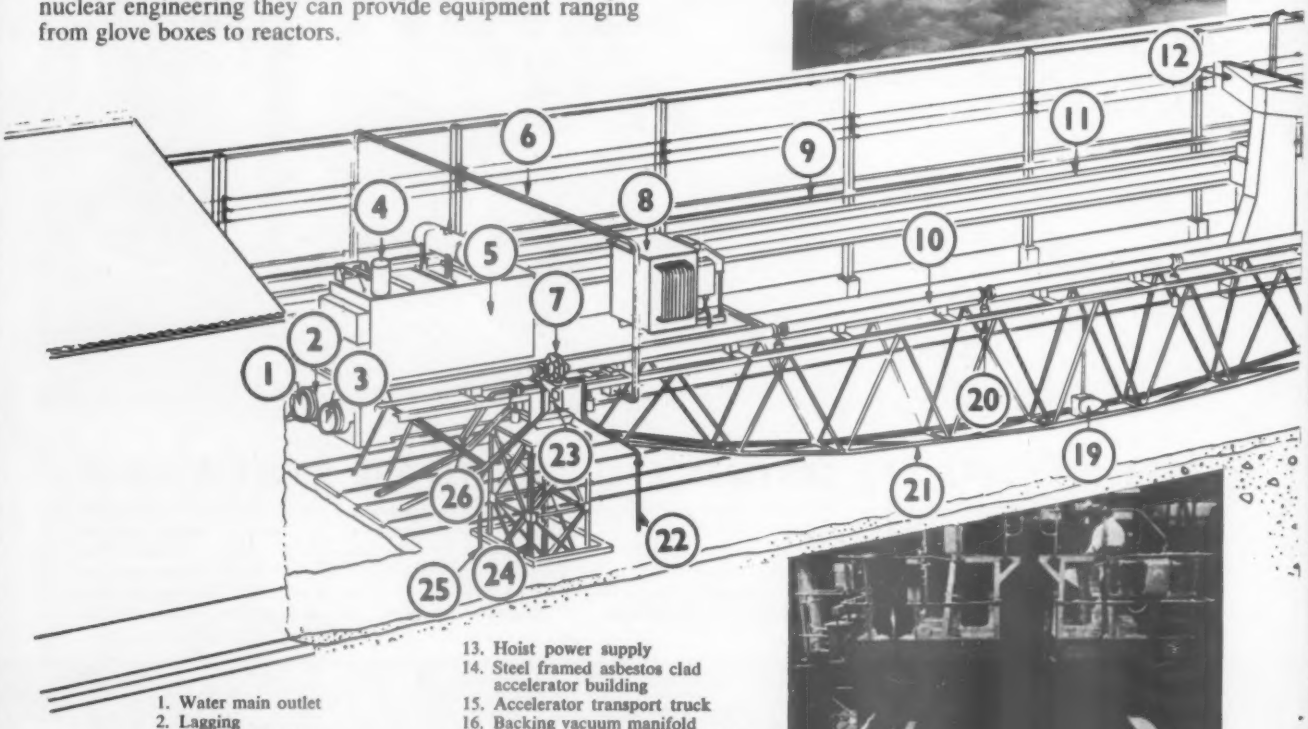
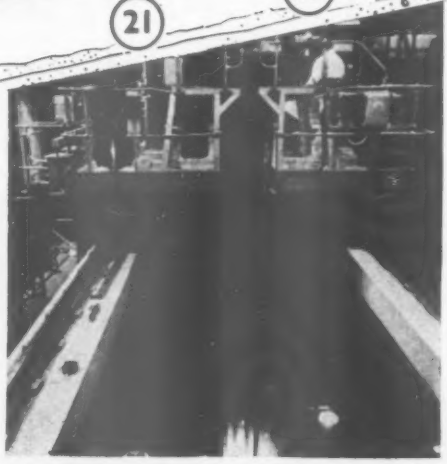


1. Water main outlet
2. Lagging
3. Water main inlet
4. Klystron
5. Klystron Modulator Unit
6. Sub accelerator R.F. feed
7. Steering coil
8. Sub accelerator power supply
9. R.F. drive line
10. Accelerator tube
11. Supply and control cable rack
12. Travelling hydraulic hoist
13. Hoist power supply
14. Steel framed asbestos clad accelerator building
15. Accelerator transport truck
16. Backing vacuum manifold
17. Support column shielding tube
18. Bitumen seal
19. Rotary vacuum pump
20. Diffusion pump
21. 20 metre sub accelerator
22. Water outlet
23. Support alignment jack
24. Support column
25. Water inlet
26. R.F. load



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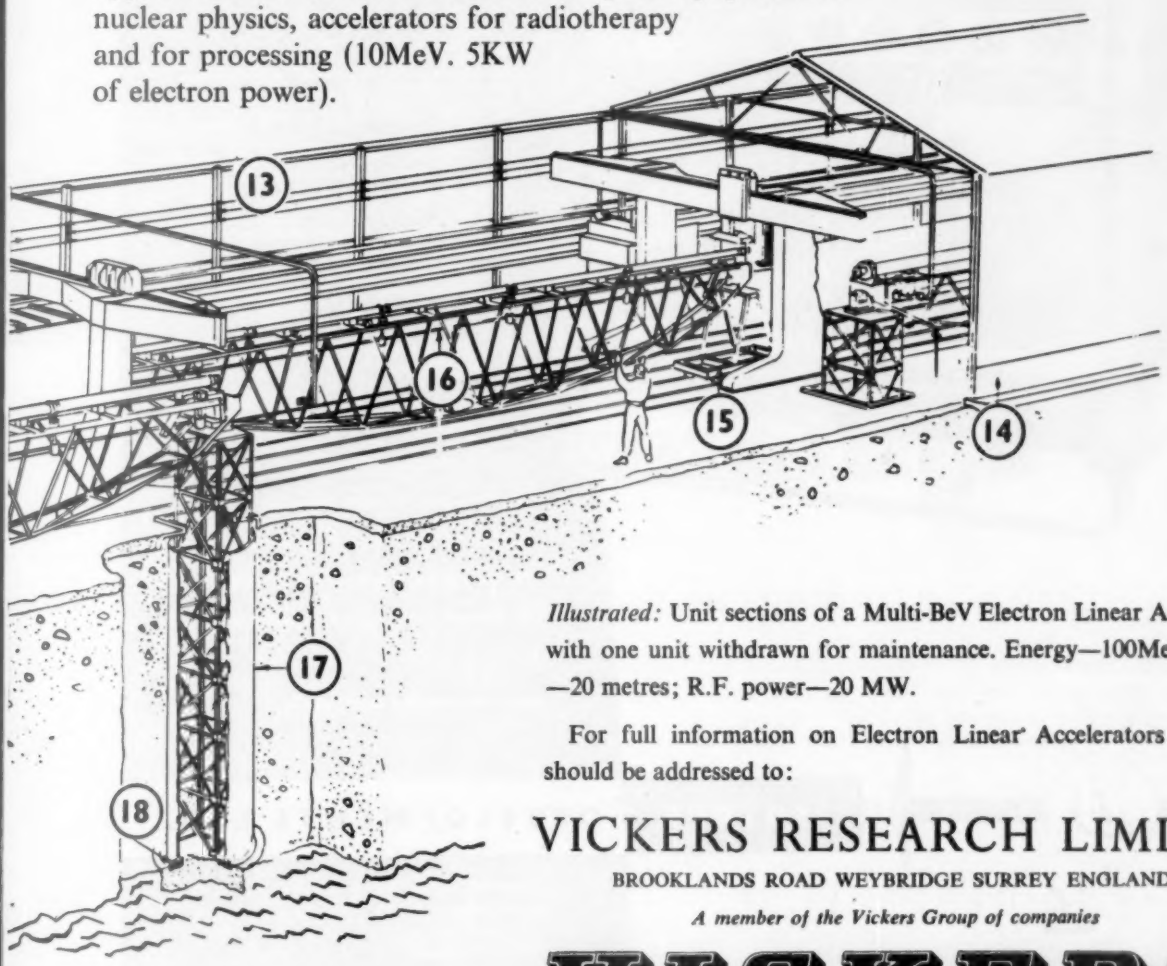

Illustrated: Unit sections of a Multi-BeV Electron Linear Accelerator with one unit withdrawn for maintenance. Energy—100MeV; length —20 metres; R.F. power—20 MW.

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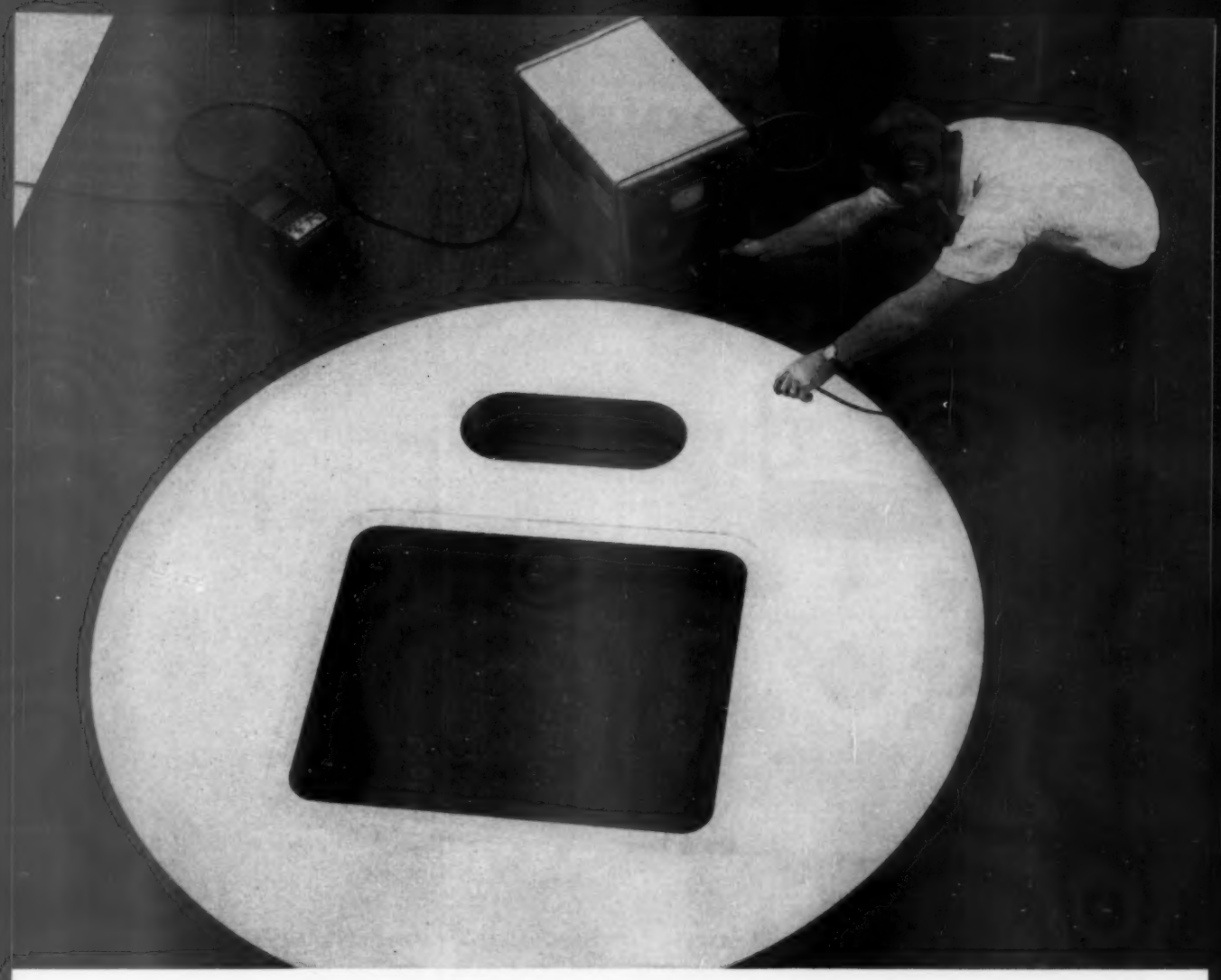

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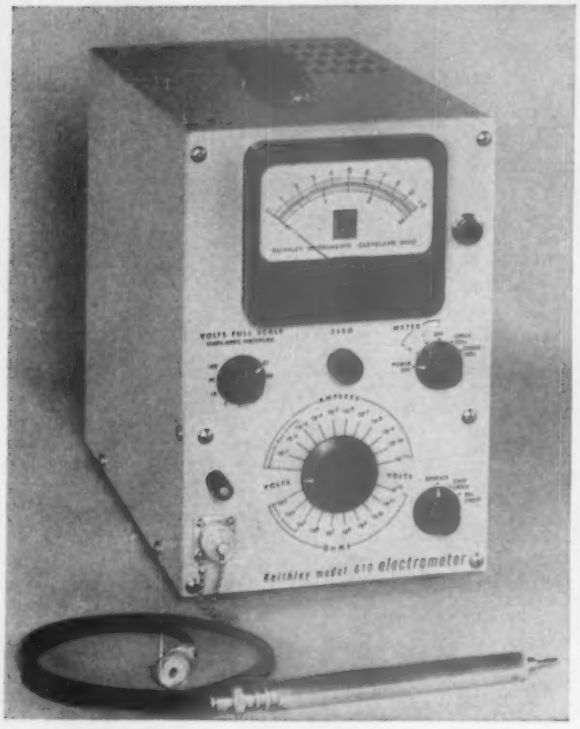

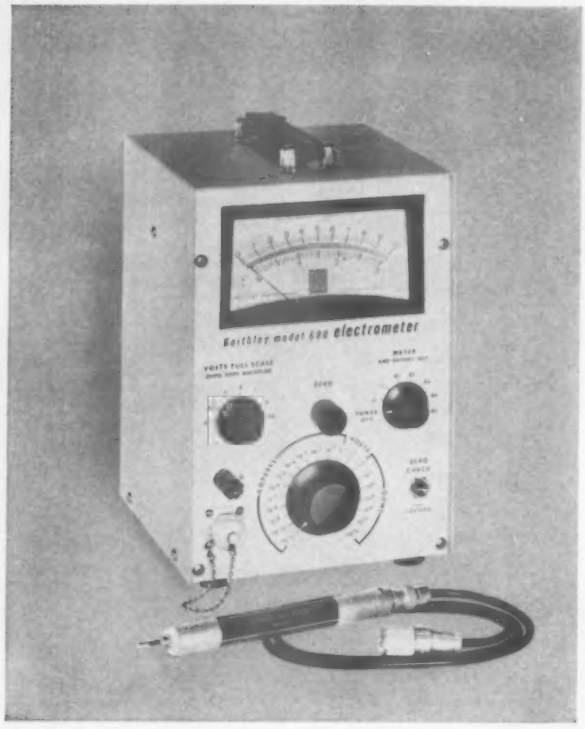

Model 610, line-operated, 59 ranges

The Keithley 610 Electrometer is a laboratory workhorse, doing the work of several instruments. It covers the extreme spans of dc voltage, current, and resistance tabulated below, and is a useful preamplifier as well. It has precise gains to 1000, a dc to 500 cps bandwidth, and 10-volt and 1-ma outputs. Input resistance of the 610 is selectable from one ohm to over 10^{14} ohms. It checks its own resistance and voltage supply standards. Zero drift is comfortably within 2 millivolts per hour after warmup.

Model 600, battery-operated, 53 ranges

The Model 600 is a small, portable, battery-operated sister of the 610. Its many ranges also are tabulated below. Like the 610, its input resistance may be varied from one ohm to over 10^{14} ohms, permitting an optimum balance of low circuit loading verus minimum pick-up. Output is sufficient to drive potentiometric recorders directly, with a dc to 100 cps band-width, and zero drift is within 2 millivolts per hour. The 600 will check its own batteries; minimum battery life is 500 hours.

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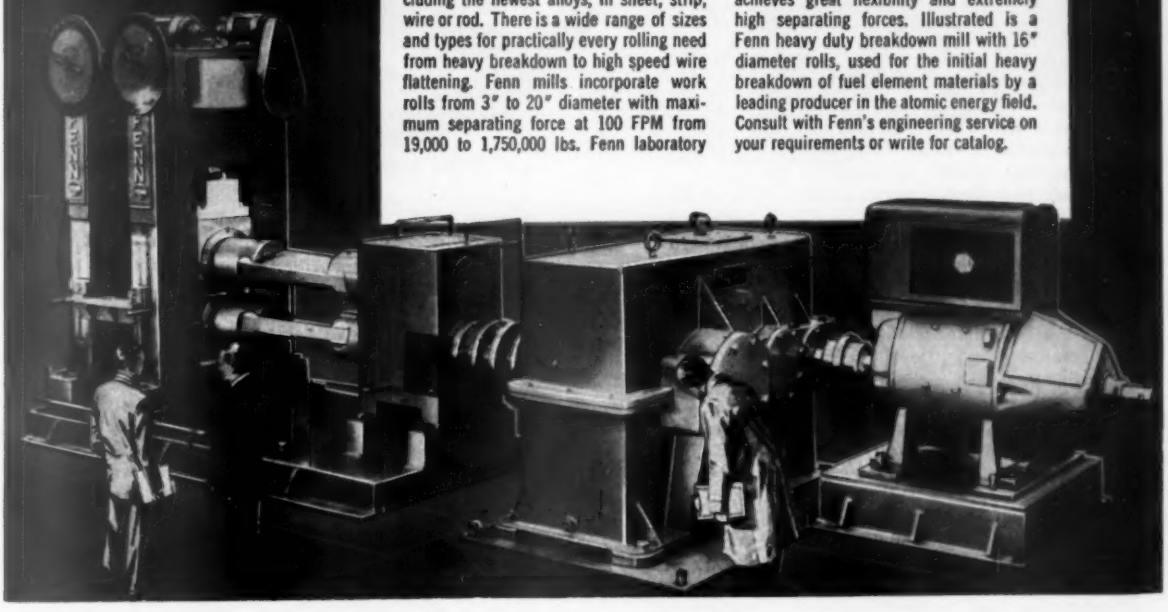
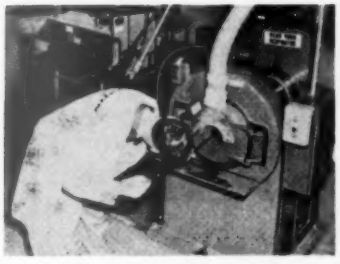


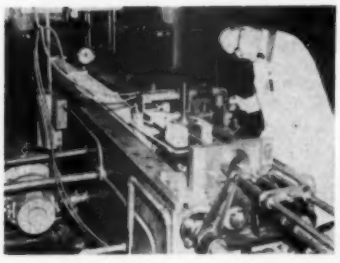
FENN SWAGING MACHINES

This Fenn Model 4F Rotary Swaging Machine is being used for sizing and pointing cermet-type fuel elements. Eight models in the complete Fenn line have capacity ranges on finished work from 5/32" to 3-3/8" on solid bar stock and up to 6" on tubing.



FENN DRAW BENCHES

Illustrated is a 25,000 pound Draw Bench used for drawing fuel elements to exact size over an arbor and then to stretch the arbor so that it can be easily moved. Fenn Draw Benches have capacities from 2,000 to 40,000 pounds pull. They are designed for use with draw dies or Fenn Turks Heads.



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"But Watson, I thought you knew I was interested in knowing the capture cross section of Gd^{156}"

Yes, I thought you already knew why I was so interested in knowing the capture cross section of Gd^{156}. You see, old boy, it's a matter of simple deduction. As commercial reactor applications come closer to reality, neutron fluxes will be increasing.

As you know, Lady Baskerville is contemplating the construction of a nuclear reactor on the moor some day. Surely, if it is to be a profitable venture, we must use materials which will perform satisfactorily, and at the lowest possible total cost.

Right now one of the important mysteries to be resolved is the selection of the optimum control rod poison. As you know, sharp decreases in costs of rare earth materials have made the use of these poisons look extremely attractive. Now you see, Watson, tests indicate that inexpensive mixtures of gadolinium and samarium or gadolinium and dysprosium have good enough resonance integrals to give quite satisfactory rod worth in most systems.

Yet, in calculating rod lifetime it is impossible to estimate performance without knowing the cross section of Gd^{156}, at least approximately. Without knowing the cross section of Gd^{156}, these physics blokes insist that it be assumed equal to zero. Hence a control rod with a surface density of 1.5 gm/cm^2 of gadolinium would absorb about 1.7×10^{21} n/cm^2 in Gd^{155} and Gd^{157} before losing its thermal blackness. This is adequate for most commercial reactors now being built, but for some of the future, higher flux machines, longer life would be highly desirable.

If Gd^{156} has a cross section of 1,000 barns, the rod mentioned above would have a capacity of about 2.3×10^{21} n/cm^2, a cross section of 2,000 barns would result in a capacity of about 4×10^{21} n/cm^2, and a cross section of 5,000 barns would yield an absorption capability of $5 \times 10^{21} n/cm^2$. So you see, Watson, either a longer lifetime or a lighter loading could be realized if the cross section of Gd^{156} were to prove substantial.

One reason I'm so interested in this cross section, Watson, is that one of the Americans did some work about 10 years ago that showed 3 atoms of Gd^{156} being consumed for every 20 atoms of Gd^{155} and 70 atoms of Gd^{157}. Thus we have a clue that the cross section of Gd^{156} may be between 5,000 and 10,000 barns. If this proves to be so, Watson, Gd^{156}, which has hitherto been indicated as a villain based on insufficient and circumstantial evidence, may in fact prove to be the hero of control rod technology. Several investigators at the laboratories are, or will soon be, researching this important matter. Please keep me informed as to their progress in analyzing the evidence.

Now really, Holmes knows and should have told Watson that Lindsay is headquarters for neutron absorbing rare earths for use in nuclear reactors.

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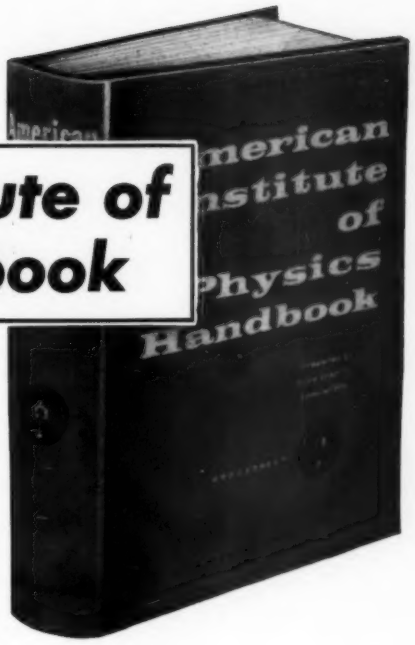

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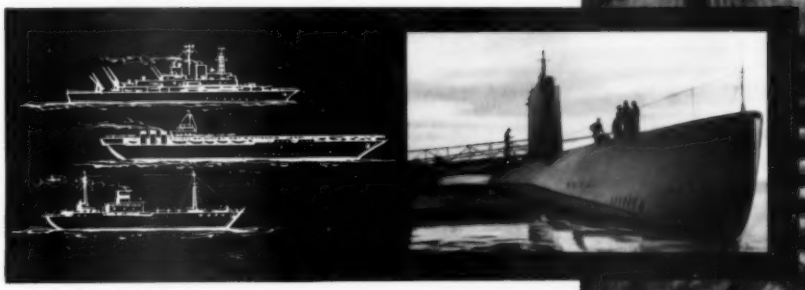

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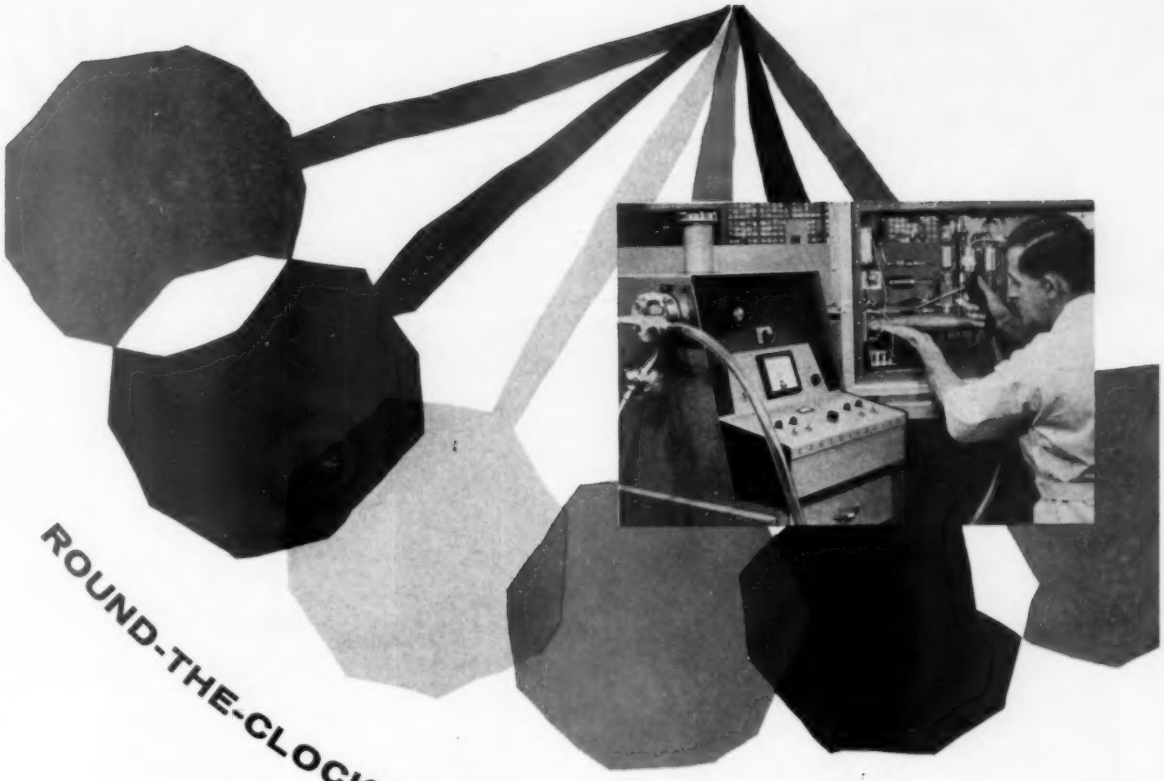

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Beltsville

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Beltsville; Langley; Ames

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Studies of fields and particles in space, investigations of the composition of planetary atmospheres, and development of instrumentation and experimental techniques for these investigations.

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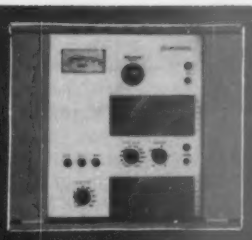

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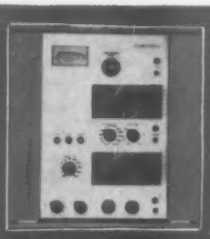

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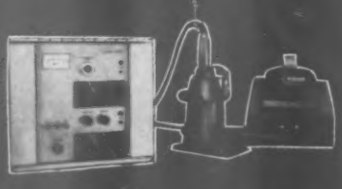

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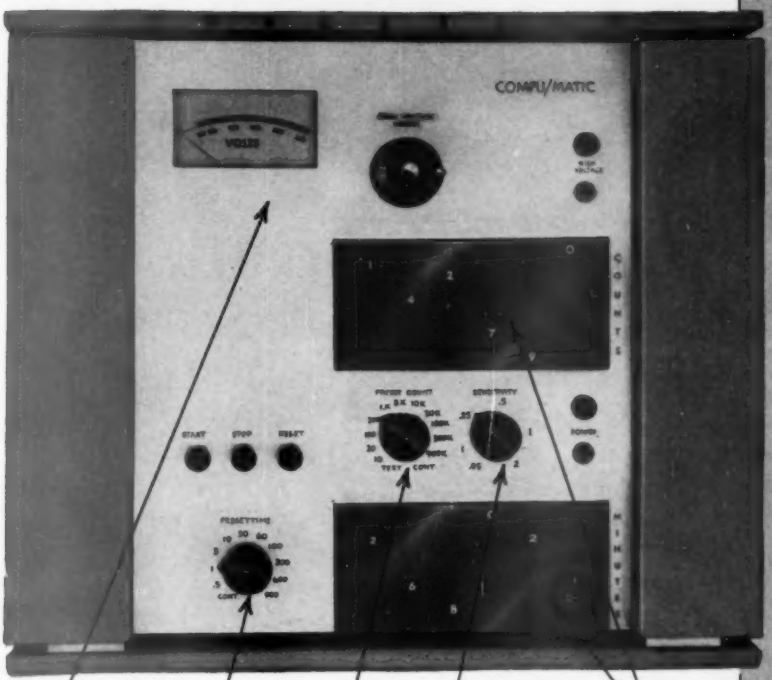

17
3000.00
5.58
537.63

18
3000.00
7.77
386.10

19
3000.00
9.08
330.39

20
2195.00
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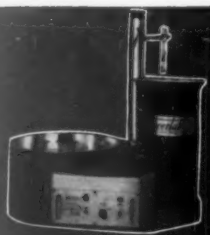
27
3000.00
4.96
604.83



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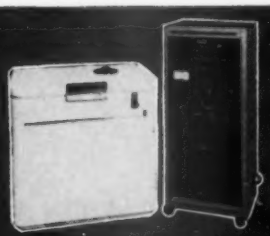

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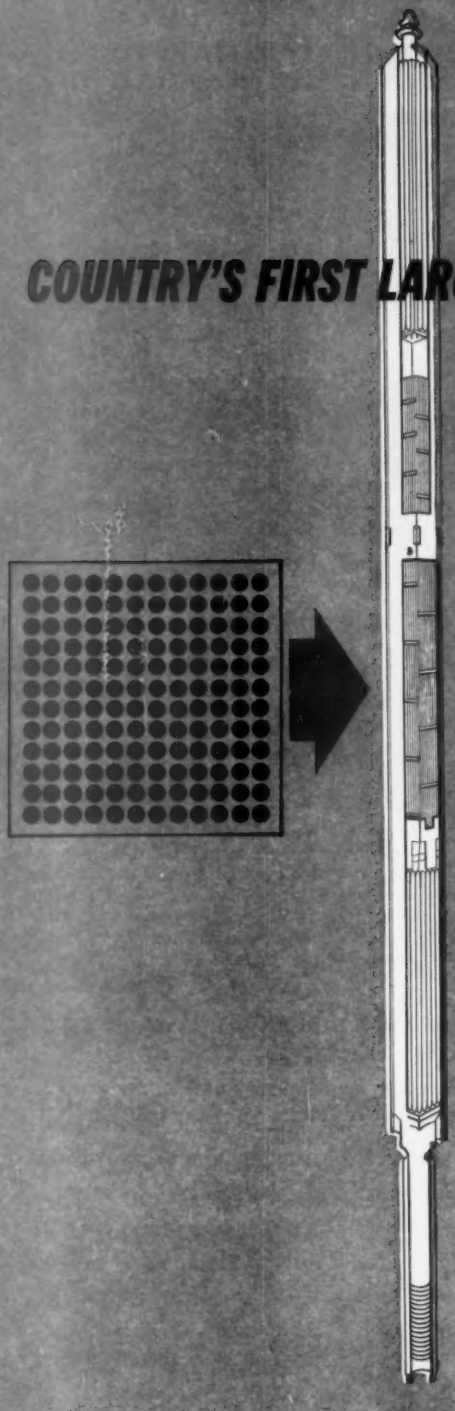

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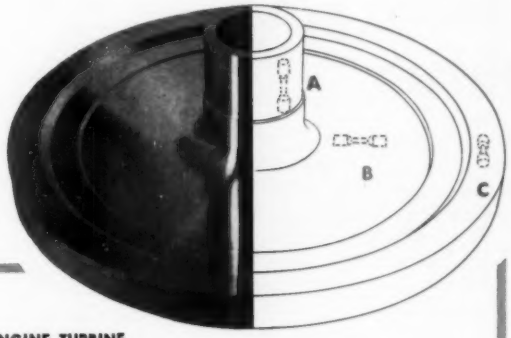
		Typical Properties			
		Tensile Strength	Yield Strength	Elongation	Reduction of Area Transverse
A	Tube, Transverse	236,000	203,000	12.7%	45.1%
B	Fork, Transverse	233,000	205,000	10.6%	31.9%



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		Typical Properties			
		Tensile Strength	Yield Strength .2% Offset	Elongation	Reduction of Area
A	Hub, Longitudinal	158,000	117,000	22.2%	40.0%
B	Web, Radial	159,000	116,000	21.3%	40.0%
C	Rim, Tangential	162,000	117,000	20.3%	39.7%

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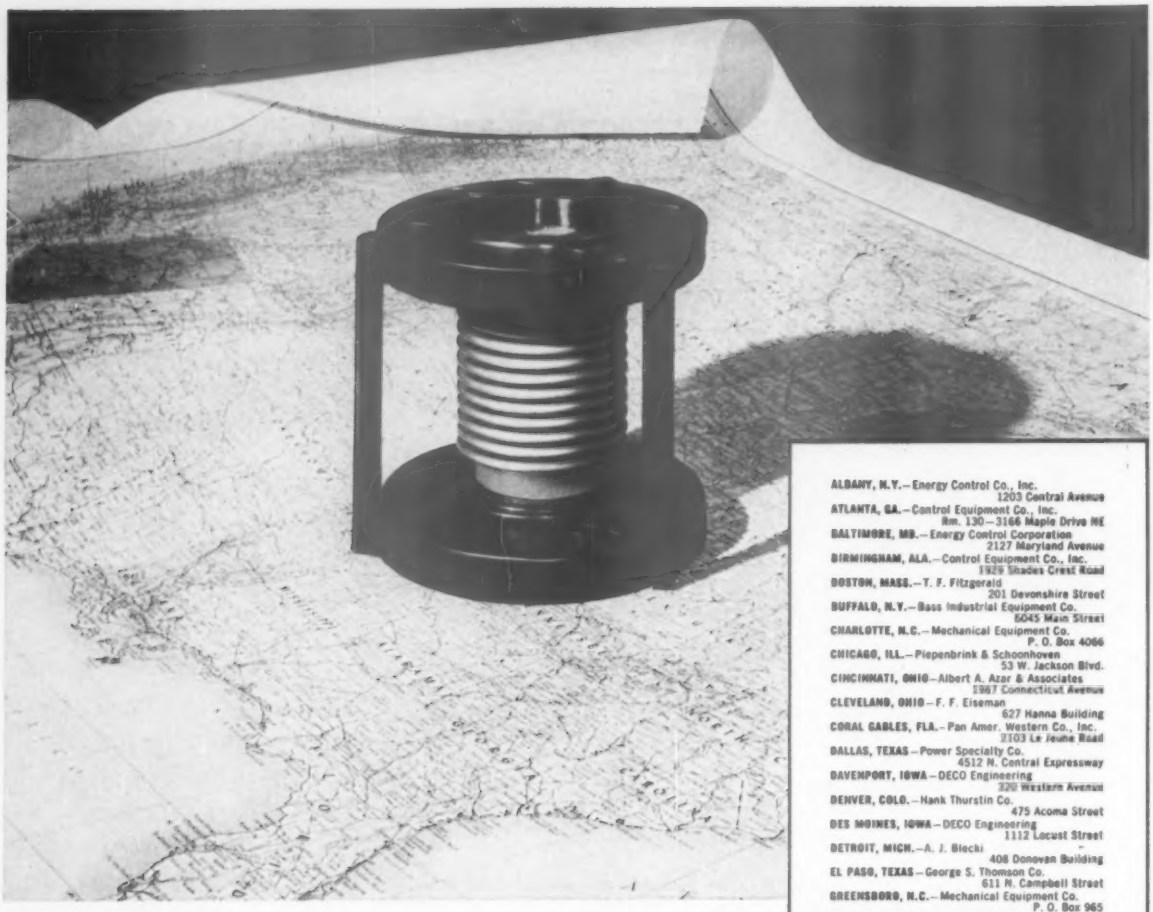

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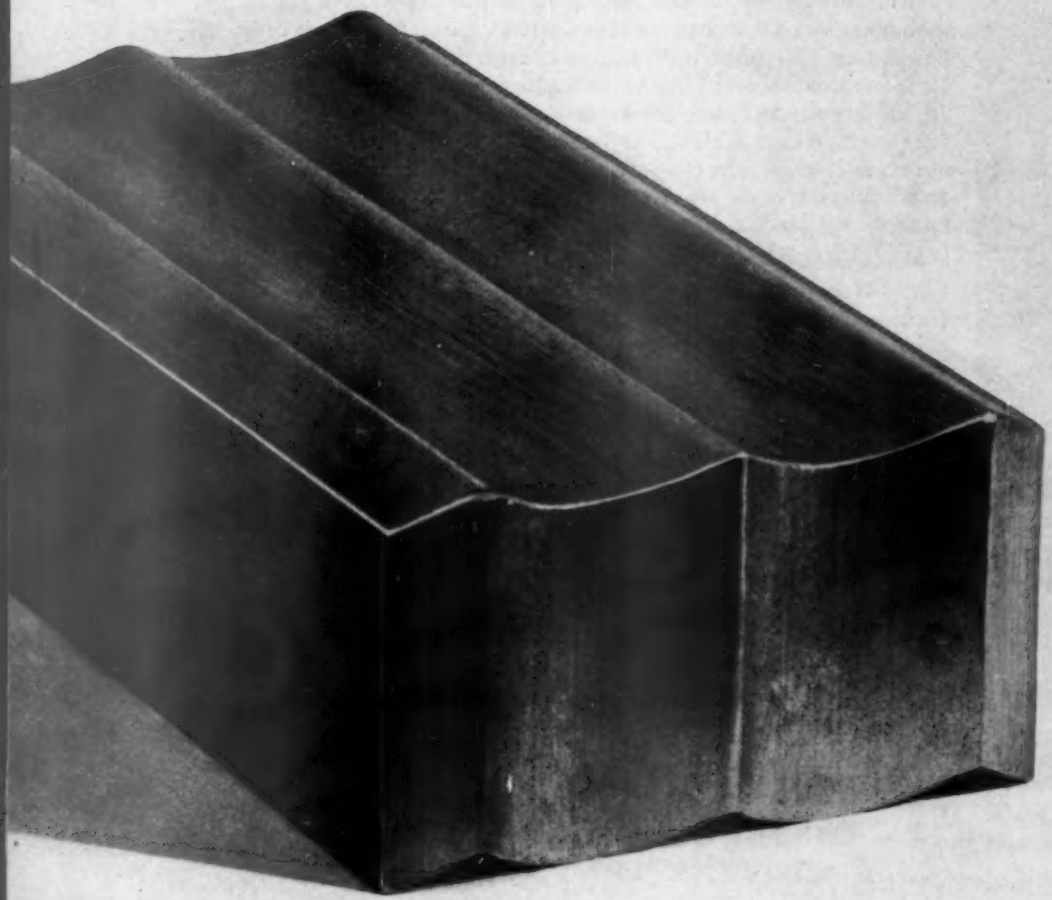

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A YEAR OF ATOMIC ACHIEVEMENT AT CURTISS-WRIGHT

IN EXPANDING the peaceful uses of the atom during the past year, Curtiss-Wright made impressive contributions toward bettering man's way of life. Here are a few of these atomic achievements in research, development and production.

At Curtiss-Wright the wide range research that eventually harnesses the atom is carried on in its own facilities. By 1957, Curtiss-Wright had designed, financed and built its own multi-purpose research reactor—its own beam room for neutron radiation—its own radiochemistry and metallurgical laboratories . . . and laboratories for the development of new reactor materials. This foresight and experience made Curtiss-Wright the logical choice in 1958 to supply nuclear research reactors to leading universities in the United States—and even on the other side of the Free World. In Thailand, a Curtiss-Wright reactor will establish that nation's atomic research program.

Now, review for a moment parts of the atomic development program at Curtiss-Wright. In 1958, Curtiss-Wright was selected by the U.S. Army to design and build a High Intensity Food Irradiation facility for exploring ways of reducing the need for refrigeration in preserving foods, in order to increase the variety available to troops in the field. Important progress was made, too, on other projects such as supplying Cobalt 60 and other gamma ray sources, together with related equipment for medical radiotherapy—and non-destructive metals testing using radiographic isotope cameras.

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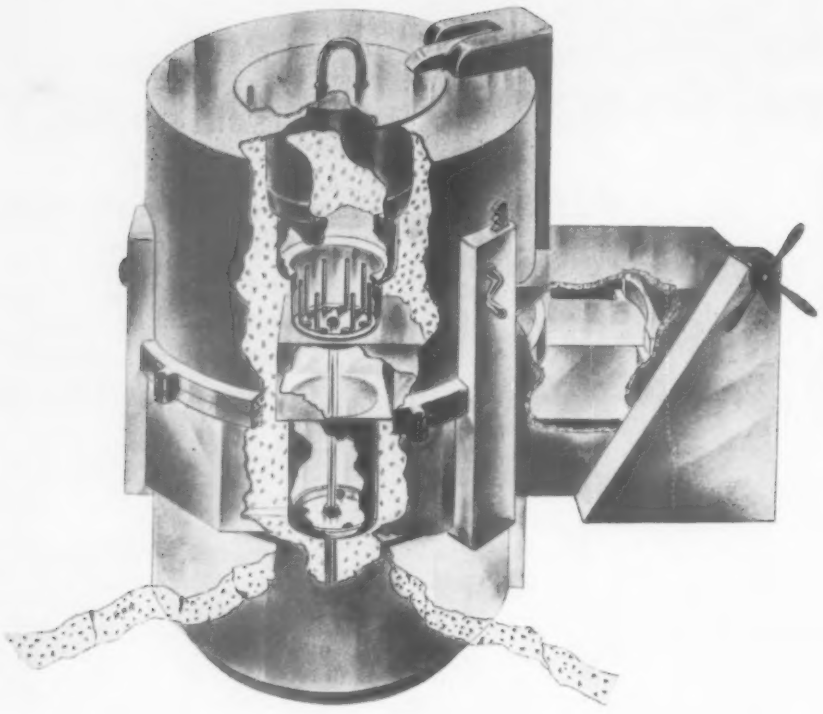

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Recently a major oil company came to Nuclear Systems with a rigorous set of specifications for a cobalt 60 irradiation facility, including:

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- *High flux level*
- *Extremely low surface dose rate*
- *Provisions for high temperature irradiations*
- *Large sample containment*
- *Variable diameter annular source*
- *Connections for lab utilities to sample*
- *Source strength—20,000 curies*

Unit must be completely self-contained—no auxiliary shielding—and completely mechanical in operation, with a series of interlocks to provide foolproof operation.

Working with their engineers and research people, Nuclear Systems came up with an approved design which met all specifications as well as A.E.C. and Bureau of Explosives requirements. The unit will be produced, tested and delivered early this Spring.

If you have a requirement for a cobalt 60 irradiation facility, Nuclear Systems offers the most complete service in the field.

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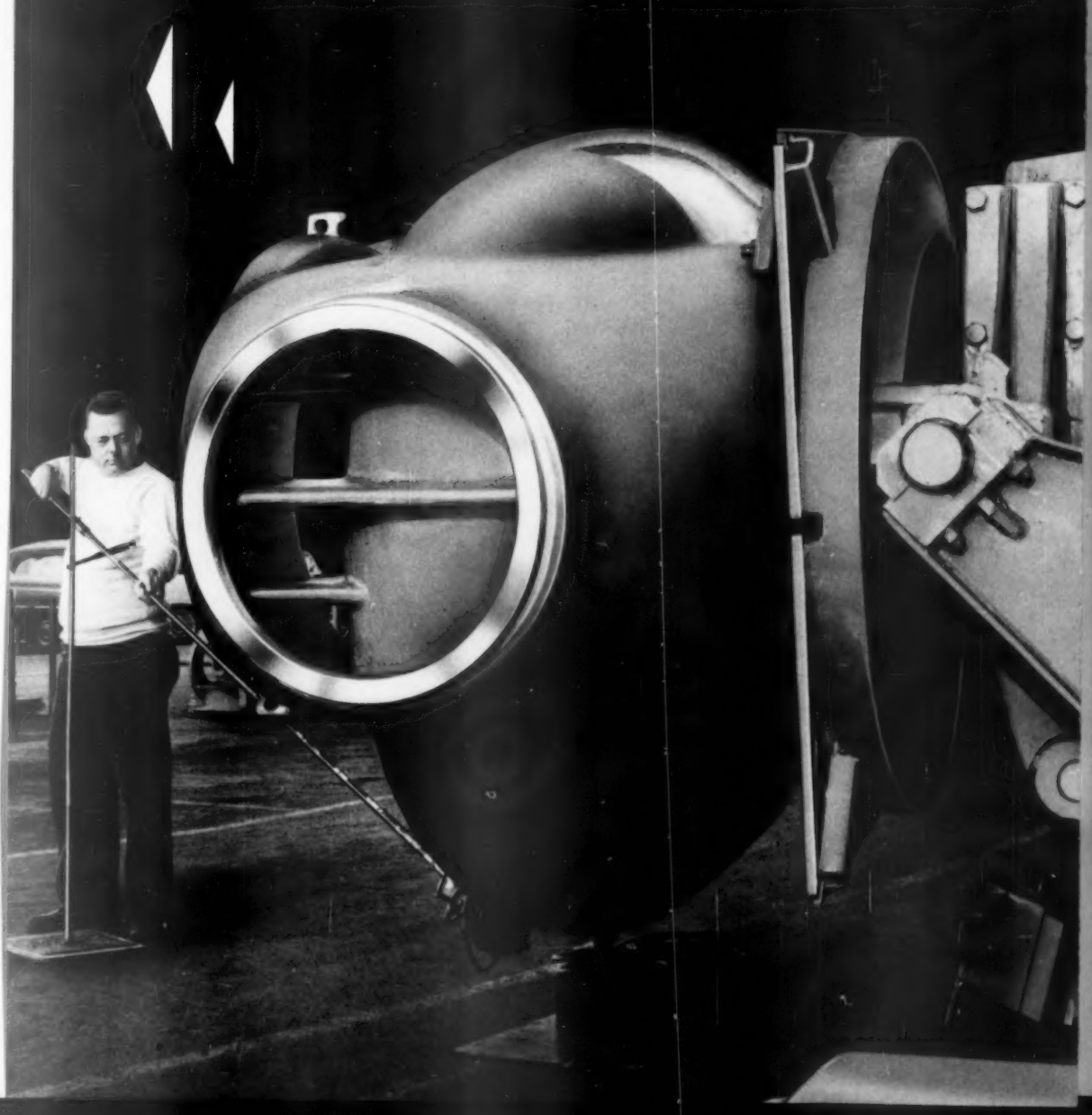


BJ Specialists in solving N

The special pumping demands of nuclear installations—whether stationary, portable or mobile—are actually a combination of many different, and usually difficult specifications.

To satisfy these complex requirements, Byron Jackson uses the same basic skills and methods which have made BJ a leader in the design and manufacture of special engineered pumps of all types for most of its 86 year history.

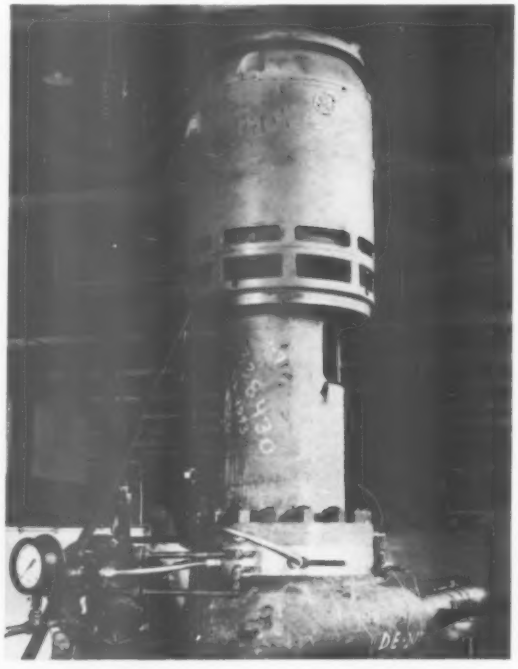
Shown below are some actual requirements for nuclear pumps which BJ engineers have successfully solved. One of these, or one of the many other BJ installations may be similar to your own needs. Our engineers always welcome the opportunity of discussing them with you.

Problem:

HIGH PRESSURE AND HIGH TEMPERATURES both were required operating conditions, along with maximum pump reliability and economy for the Dresden Nuclear Power Plant of the Commonwealth Edison Company.

Solution:

Shown here on a hot loop test in BJ's laboratory before delivery, this mechanically-sealed pump meets all specifications of handling de-mineralized water to 1250 psig suction pressure and at temperatures to 574°F. It delivers 1700 gpm at 130 foot total discharge head.



Problem:

SELF-VENTING ZERO LEAKAGE pump for high pressure, high temperature operation on General Electric's Hanford experimental water loop.

Solution:

The BJ hermetically-sealed liner-motor design with double thrust bearings allows self-venting inverted operation of this 45 H.P. pump for dependable, zero leakage performance at 2500 psig, 650°F.

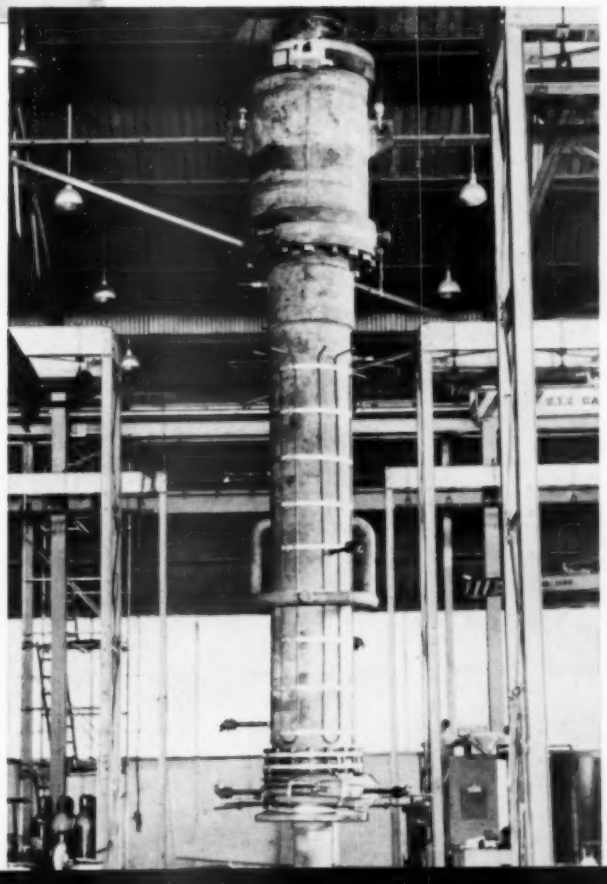
Nuclear Pumping Problems

Problem:

REACTOR SAFETY—In the event of a power interruption or failure on General Electric's Hanford Plutonium Recycle Test Reactor, the primary coolant pump would decelerate faster than the automatic control mechanism could complete the reactor shutdown action. A critical high temperature condition could occur before it could be corrected.

Solution:

This BJ Mechanically-Sealed Pump was designed with an integral flywheel for a controlled decay curve, assuring circulation until the reactor is safely shut down. It handles heavy water at 550°F under 1500 psig.



Problem:

PUMPING 1000°F BISMUTH—with zero cover gas leakage posed a problem for the Brookhaven National Laboratory. An important additional requirement was a practical means of inspection and maintenance.

Solution:

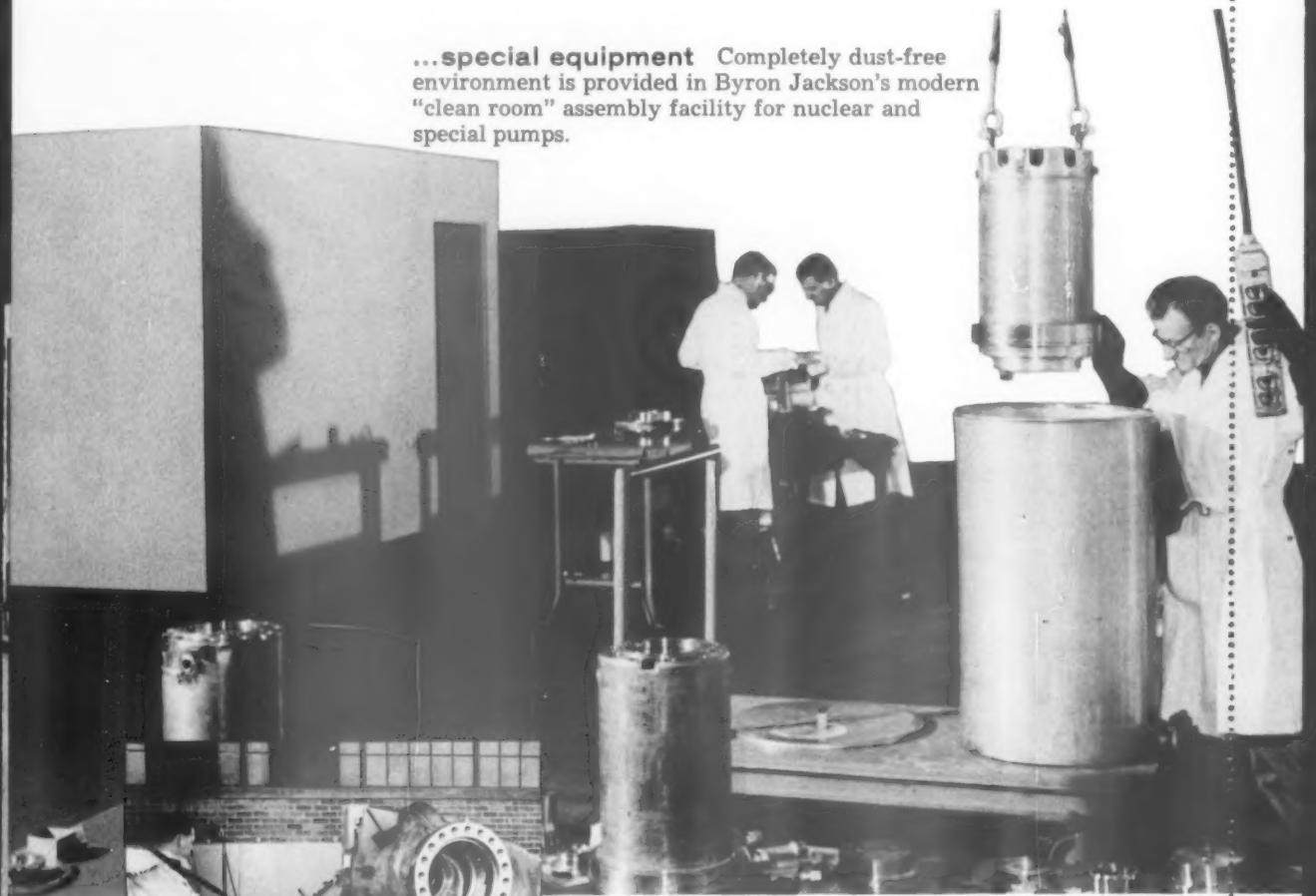
Using a hermetically-sealed, gas-filled motor, this BJ design accommodates the entire bismuth expansion at all system temperatures, and requires no liquid level controls. Its full length pull-out construction allows simplified removal by remote handling equipment for maintenance or inspection.

Nuclear Pumps

Byron Jackson experience, *plus*

...special designs From the world's largest liquid sodium pumps—(three 1000 HP, 12,000 gpm units)—to a compact ¼ HP liner-motor unit—BJ designs for the job. The success of these nuclear pump designs is proved through the installation or specification of BJ pumps on every major commercial reactor in the United States.

...special equipment Completely dust-free environment is provided in Byron Jackson's modern "clean room" assembly facility for nuclear and special pumps.



...special techniques This radiographic X-ray is only one of the continuous inspections that insure reliable performance. Special welding, helium leak testing, and BJ's hydraulic hot and cold test loops provide further quality control.

Byron Jackson Pumps, Inc.

SUBSIDIARY OF BORG-WARNER CORPORATION

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BJ

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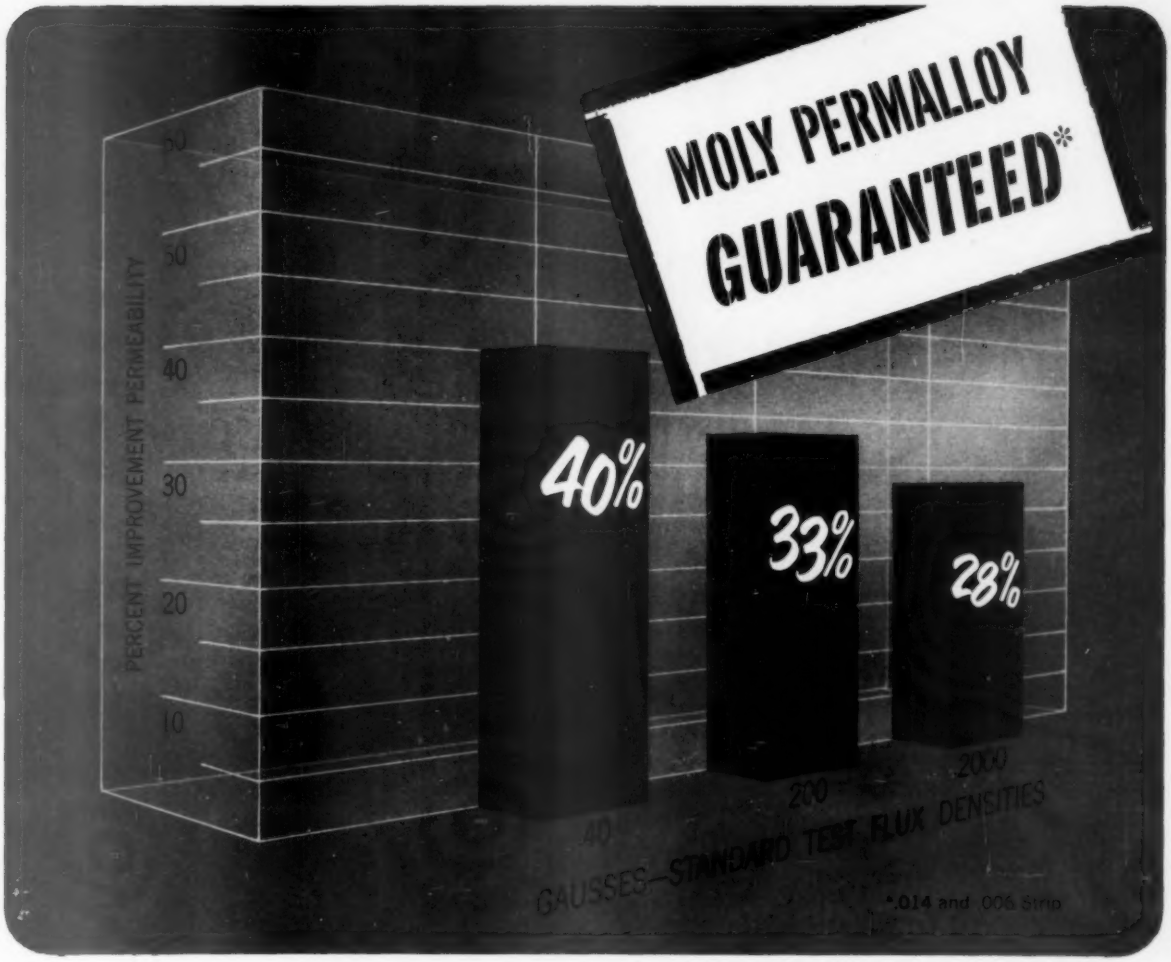
Experience**—the added alloy in **A-L Stainless, Electrical and Tool Steels



GUARANTEED PERMEABILITY OF MOLY PERMALLOY...

at values higher than old average specifications

Molybdenum Permalloy nickel-iron strip is now available from Allegheny Ludlum with *guaranteed* permeability values. And the new guarantees are much higher than the old typical values. This exceptionally high quality means absolute uniformity for the user—new consistency and predictability for magnetic core performance.

Improved permeability of A-L Moly Permalloy is the result of Allegheny's program of production research on nickel-bearing electrical alloys. A similar improvement has been made in AL-4750 strip steel. Research is continuing on silicon steels including A-L's famous Silectron (grain oriented silicon steel), plus other magnetic alloys.

Another plus in dealing with Allegheny Ludlum is the operation of complete lamination fabrication and heat treatment facilities. A-L's years of experience in producing quality laminations result in practical know-how in solving problems common to core materials.

This working knowledge is available to all. Give us a call for prompt technical assistance on *any* problem involving electrical steels, laminations, or magnetic materials. Write for more information on A-L Moly Permalloy. ***Allegheny Ludlum Steel Corporation, Oliver Building, Pittsburgh 22, Pa. Address Dept.*** NC-16

WSW TEYS

ALLEGHENY LUDLUM

STEELMAKERS TO THE ELECTRICAL INDUSTRY

Export distribution, Electrical Materials: AIRCO INTERNATIONAL INC., NYC 17

Export distribution, Laminations: AD. AURIEMA, NYC 4

- *only 8¾" high*
- *uses interchangeable plug-in logic units*
- *provides complete versatility and portability*

. . . A Transistorized 256-Channel Pulse Analyzer

MODEL CN-110
256-CHANNEL ANALYZER
WITH PLUG-IN MODEL 210
PULSE HEIGHT ANALYZER UNIT

THE BASIC CN-110 IS THE MEMORY containing all the elements for complete magnetic core data storage — memory current drive, cycle control binaries, address and arithmetic binaries, power supplies, etc.

PLUG-IN LOGIC UNITS make several different analyzers available in the time it takes to interchange units. Standard plug-in units are available for Pulse Height Analysis, Time of Flight Measurements, Count as a Function of Time; units for special programs can be built to order.

CARRY THE SYSTEM TO THE OPERATION — the completely transistorized Model CN-110 weighs only *40* lbs. (including logic unit), and is only *8¾"* high. It is easily carried by one person to any location. With auxiliary readout system, total weight is approximately 100 lbs. — over 1500 lbs. less than equivalent systems using vacuum tubes.

NO COOLING PROBLEMS — the complete use of transistors in the Model CN-110 reduces heat dissipation — air conditioning or bulky blowers are not required; total power less than 10 watts.

MANY TYPES OF READOUT may be used — analog . . . binary . . . octal and decimal. Data can be recorded on strip chart or X-Y recorders . . . printed paper tape . . . magnetic computer tape . . . punched paper tape . . . punched cards. The Model 220 *Decimal Converter*, available as an accessory, is designed specifically for use with the CN-110. It includes a paper tape printer which prints channel number and count number on the same line (with 3-space separation). During the counting period, the Model 220 also functions as a live time indicator and automatic dead time corrector.

Write for complete data on the Model CN-110 and standard plug-in logic units. For details on custom logic units and data readout programmers, outline your specific requirements.

TMC **TECHNICAL MEASUREMENT CORPORATION**

441 WASHINGTON AVE., NORTH HAVEN, CONN.

Let CB&I Experience

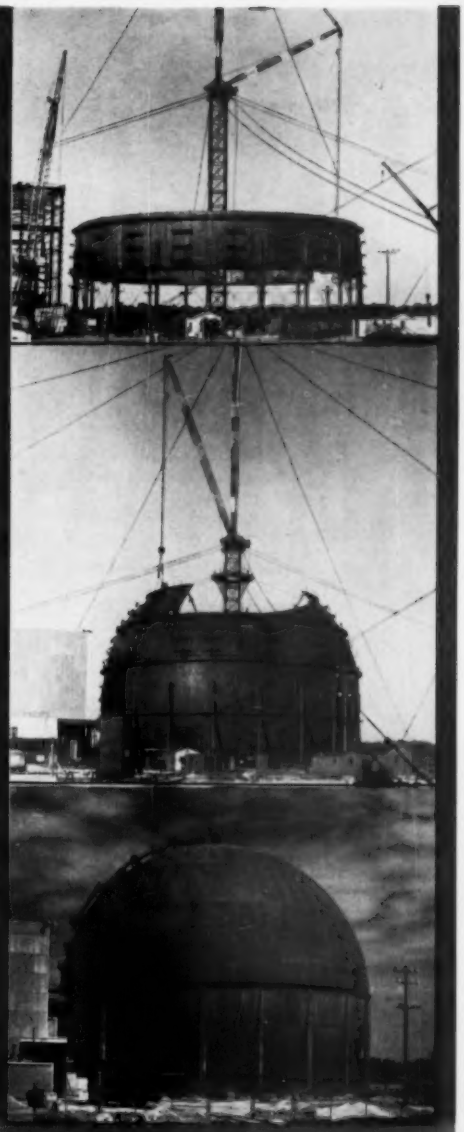
help to shape your atomic future

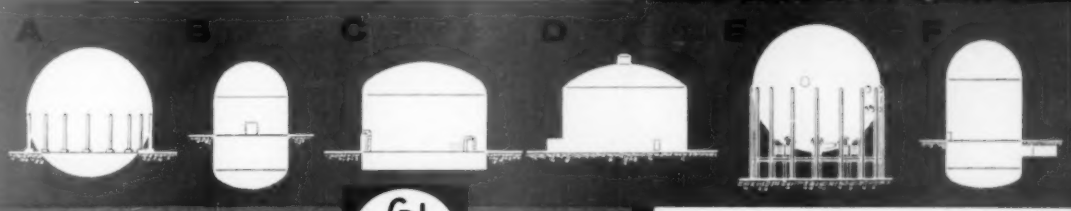
It takes more than a pioneering spirit to build atomic vessels. CB&I's pioneer vessel, an atom smasher for the University of Minnesota, was 16 years old when we completed the "Big Sphere" — 225 feet in diameter — for Knoll's Atomic Laboratory. Since then, 9 additional steel reactor housings have been completed, or are under construction, by CB&I.

These years of research, together with engineering, fabrication and erection for the atomic industry, have brought new experiences . . . even to a company with seven decades of craftsmanship in steel.

CB&I's experience can be of great value to firms which rely on precision-engineering structures. It will pay you to learn *more* about CB&I's *coordinated* services. Write our nearest office for the brochure: *Craftsmanship in Steel.*

THE DRESDEN SPHERE a new sound-color film traces fabrication and erection of a 190-foot sphere. Showings will be arranged upon written request.





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N-1

There's plenty of room at the top

. . . but there's lots more room

at the bottom

Look around you. How many men do you see at about your job level and income? Know them pretty well, don't you? Are they smarter than you are? Do they work any harder? Do they possess some "something" that you don't have?

No, of course they don't. And yet, five years from now, some few of you are going to be lots closer to the top of your company. There's lots of room up there — management needs able-brains as never before. But, warning! There's still lots more room at the bottom!

Is there a shorter, surer route to that better job, that bigger paycheck, that pride of achievement? There is, but it's no Easy Street. You still have to supply the energy and effort. How? By digging in zealously with a more intensive, regular reading of the magazine you're holding in your hand right now. Look ahead, read ahead, get ahead.

McGraw-Hill editors write it exclusively for you. Nobody else. It's all about you and your job and your problems. Nothing else. News, fact, trends — today's tasks and tomorrow's opportunities. As inspiring as it is informative. Reads lively. Keeps you on your toes. Makes important people notice you. What's more — you'll enjoy it . . . for it's just about as personal as any publication could ever hope to be.

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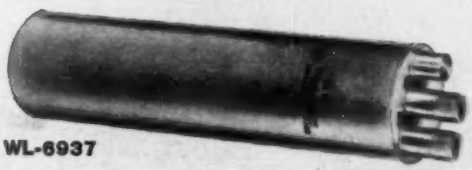
The most interesting reading for the man most interested in moving ahead

Westinghouse tube engineering...
serving the nation through imagination

The proven performance record of WESTINGHOUSE NEUTRON DETECTORS!

WL-6377



WL-6937

WL-6376

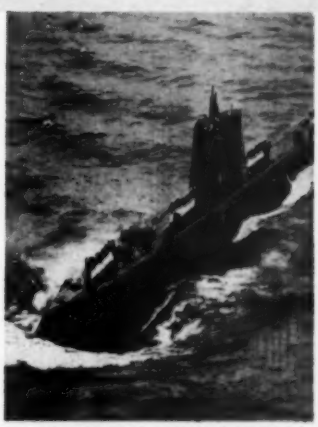
WL-6307

Compensated Ion Chamber—WL-6377—In production for over five years. Operating reliably in more than 20 power reactors and 20 research reactors. Designed into more than 30 power reactors and 10 research reactors under construction.

Fission Chamber Class—WL-6376, WL-6941 or WL-6971—In production for over five years. Operating reliably in more than 10 power reactors and 20 research reactors. Designed into more than 20 power reactors and 10 research reactors under construction.

Uncompensated Ion Chamber—WL-6937—In production for over two years. Operating reliably in more than 15 research or test reactors. Designed into more than 15 research or test reactors and two power reactors under construction.

Proportional Counter Class—WL-6307, WL-6998, WL-7087 or WL-7243—In production for over five years. Operating reliably in more than 10 power reactors and 2 research reactors. Designed into more than 30 power reactors and 2 research reactors under construction.



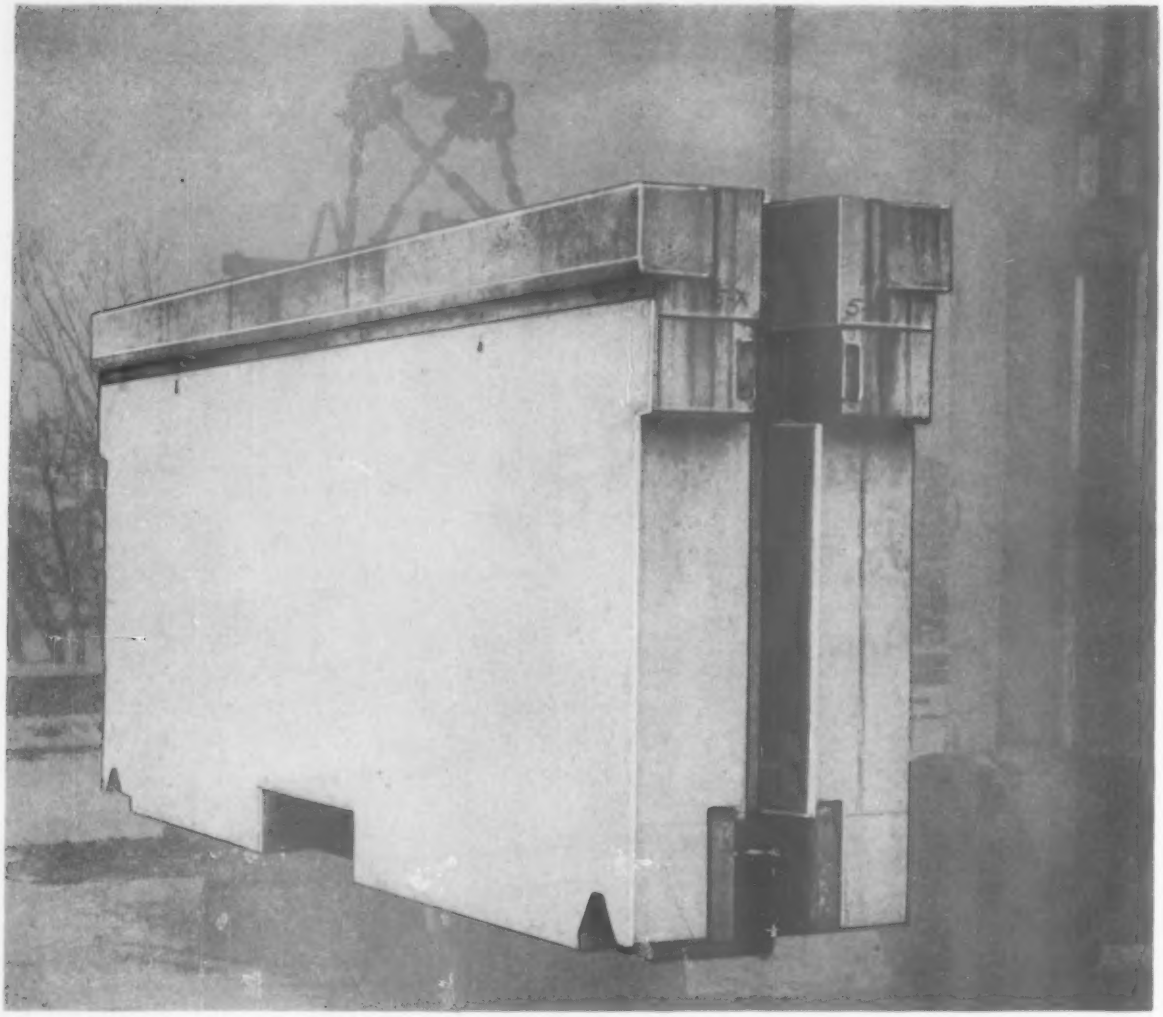
The Nuclear-Powered Submarine is one of many applications where Westinghouse neutron detectors have earned an outstanding performance record.

NOTE: *Westinghouse's high temperature detectors will be ready soon. See them at the Atom Fair in Cleveland, April 6-10.*

YOU CAN BE SURE...IF IT'S

Westinghouse

Electronic Tube Division Elmira, N.Y.



37,000 lbs vertical lift concrete shielding door

ONE OF FIVE ENGINEERED AND FURNISHED COMPLETE WITH OPERATOR BY AMERAY FOR THE NASA REACTOR, SANDUSKY, OHIO

The steel reinforced, solid concrete barrier door pictured above was cast in a continuing pour to ±⅛" tolerance.

Physical Dimensions

Length	14 ft
Height	6 ft
Thickness	3 ft

To operate this door, Ameray engineered and furnished the complete electrical drive mechanism as well as the 16" solid steel lower barrier doors.

Ameray's experience in the design, engineering, development and installation of nuclear products enables us to offer the widest possible line of radiation protection products for both standard and custom requirements.

For a complete description of the hundreds of Ameray Nuclear Shielding Products, write today for our new 72 page catalogue.

Another Product Safety Engineered by

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CORPORATION

70 ROUTE 46, KENVIL, N. J. FOXCROFT 6-4100

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IN SRE... Zallea expansion joints absorb thermal expansion of reactor core tank and outer tank

The very nature of the Sodium Reactor Experiment, conducted by Atomics International for the AEC, and the method of handling the liquid sodium reactor coolant demand reliability in expansion joints. Because of the operation there can be no compromise in design or quality.

The high temperature SRE uses Zallea Expansion Joints where thermal expansion must be absorbed and where a gas seal must be maintained. An 11-ft. diameter Zallea Expansion Joint at the top of the outer tank absorbs the expansion that results from the temperature increase in these components as the reactor comes up to operating temperature, 960°F. In addition, the expansion joints form a seal for the helium gas and sodium vapor above the sodium pool at the top of the reactor as well as for the helium gas within the outer tank.

In the sodium coolant piping circuit gas seals are effected by means of Zallea Expansion Joints in the region where the pipes leave the reactor cavity and enter the pipe galleries.

Zallea has worked with almost every major engineering and manufacturing firm engaged in atomic, nuclear and missile work—and has provided the large majority of expansion joints for such projects. As a result, we have accumulated a store of expansion joint engineering data and manufacturing skills that cannot be equalled. Whenever expansion is involved in piping systems, reactors, tanks—whatever the application—let our engineers work with you. We already have the answer to many of the difficulties you will encounter. And we welcome the chance of tackling your problem.

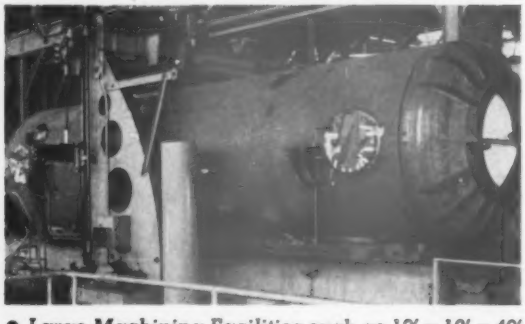
Zallea
expansion joints

ZALLEA BROTHERS, Wilmington 99, Del. • World's largest manufacturer of expansion joints

Welding for *Nuclear Component Production* demands exceptional *Facilities and Abilities*

• **Experienced** *Project Engineering*

• *Grade A Clean Room*



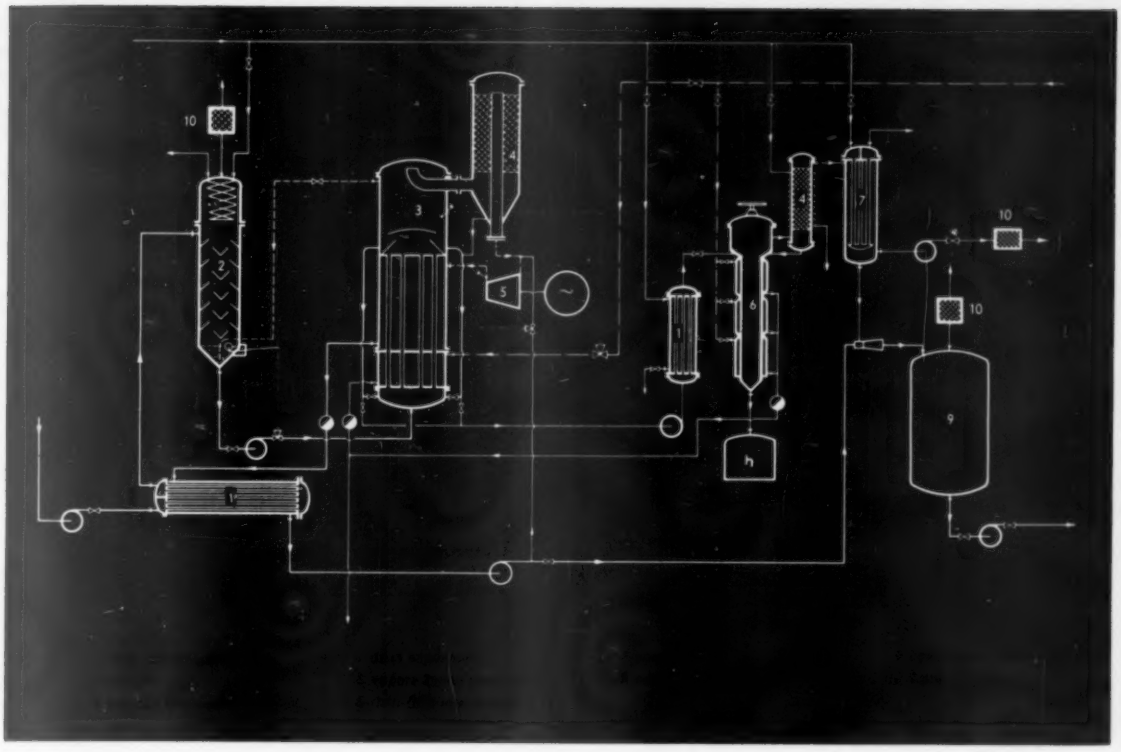
• *Large Machining Facilities such as 10' x 10' x 40' Planer*

In this young, swiftly advancing field, Avery and Saul has already recorded enviable experience in welding, machining and assembling of Nuclear Components. The company has built a talented team of technical personnel, plus a depth of superb facilities . . . strict prerequisites in dependable, knowledgeable manufacture of complex nuclear fabrications.

We invite your inquiries.

Avery & Saul
COMPANY

115 RINDGE AVENUE EXT., TEL. UNiversity 4-9070, CAMBRIDGE, MASS.



DECONTAMINATION PROBLEMS? We are experienced specialists in this field of nuclear engineering.

After having constructed the decontamination plants for the German reactor stations in Munich, Berlin and Karlsruhe we have now secured an order for

Cooling water clean-up and decontamination for the first German nuclear power plant.

This project of RWE at Kahl/Germany involves a 15 MW boiling water reactor which will be built by AEG and General Electric.

Jointly with another firm PINTSCH BAMAG AG. have developed special thin-film evaporators with maximum purification factor for decontamination plants.

Dry radioactive concentrate can be drawn off from this dual-stage evaporator with vapors recompression. Therefore you don't have to worry about chemical composition and salt content of your "hot" water.

More than 50 years experience in chemical engineering, one of the first German Companies engaged in nuclear engineering.

PINTSCH BAMAG
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Represented in the USA by Columbia Technical Corp.
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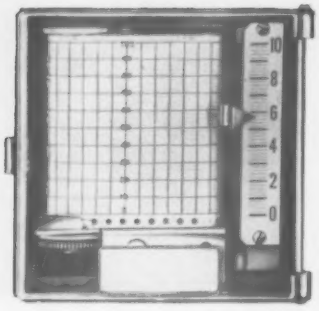
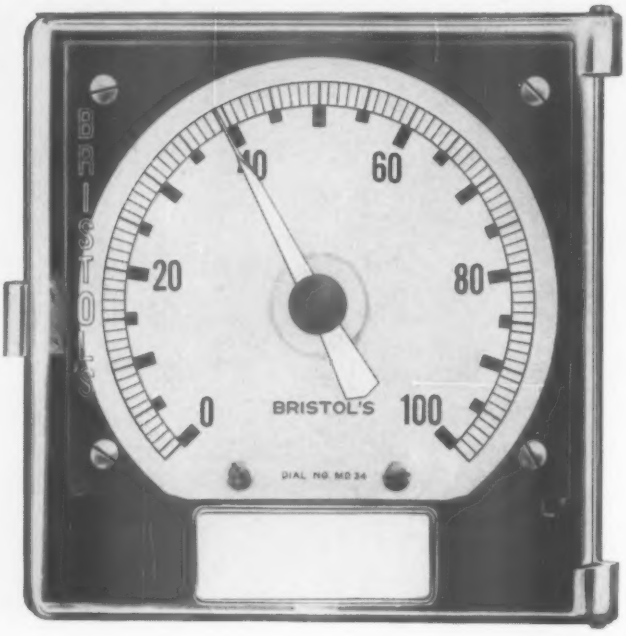
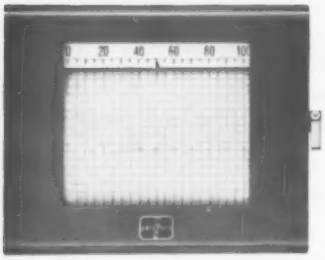


BRISTOL Indicating Electronic Dynamaster* Potentiometer and Bridge (shown below) has 8" effective scale length. Recording Electronic Dynamaster (left) has 3" chart. Panel sizes: Only 5" x 5⅛".



miniature electronic POTENTIOMETER and BRIDGE INSTRUMENTS

for nuclear power and test reactors



Large-scale Dynamaster—11" chart.

The now-famous Shippingport, Pa., Atomic Power Station... The Bristol Company is one of the instrument suppliers.

More and more reactors are going on the line under Bristol measurement and control, and they're specified for many more under construction.

Miniature Bristol Electronic Dynamaster* Indicators and Recorders, furnished as either potentiometers or bridges, can measure any variable that can be transduced to an electrical quantity... **pressure, flow, temperature, liquid level, pH, and conductivity.** Already, in the nuclear industry as in hundreds of others, these high-precision miniature instruments are establishing an outstanding record for reliability, consistent performance, and utmost flexibility. Here are just a few reasons why:

FULL PLUG-IN FLEXIBILITY. You can interchange chassis in ten seconds... replace it with either recorder or indicator instruments... both plug in easily without tools. Chassis also pulls out to intermediate position for chart changing and inking without disconnecting from circuit. Easy range change, too.

These features simplify planning of graphic control panels. Fifteen miniatures mount in less space than two full-sized units. The Bristol Company, 147 Bristol Road, Waterbury 20, Connecticut. 9.5

**T.M. Reg. U.S. Pat. Off.*

BRISTOL TRAIL-BLAZERS IN PROCESS AUTOMATION

AUTOMATIC CONTROLLING, RECORDING AND TELEMETERING INSTRUMENTS

Fansteel Announces the First Space-Age Breakthrough in the Fabrication of Tungsten!

Tungsten! *By Deep Drawing!*

Tungsten! *By Spinning!*

Once again, Fansteel has unlocked the door to unlimited new uses for a valuable metal! Now we have ways to fabricate tungsten into involved shapes heretofore impossible . . . and through such economical processes as spinning, deep drawing, hot extrusion and forging!

Now . . . tungsten—with its melting point of 6152°F., highest of all metals, its terrific strength at high temperatures, its outstanding density of .697 lbs./cu. in.—can be exploited to the fullest. Great advances can now be made in the fields of missiles, nucleonics, aviation, medicine . . . even consumer products. Fansteel has broken through to the secret of fabricating tungsten . . . its potential is now unlimited.

Imagine rocket nozzles with tungsten's fabulous heat/strength properties. Or a tungsten-encased atomic power plant weighing just five pounds. Picture a pure tungsten gyroscope rotor, almost 25% smaller than is now possible, yet retaining complete functional reliability due to its low coefficient of expansion.

Tungsten electronic tube components, tiny wristwatch flywheels and thousands of other applications are now also feasible with Fansteel's tungsten fabrication know-how.

This revolutionary knowledge is so new that we can't supply bulletins, technical information, or other printed data. But our engineers will be glad to cooperate with your own designers and production people in adapting tungsten and these new fabricating techniques to your part or product. Just send print, part samples or call in the Fansteel representative.

FANSTEEL

HIGH TEMPERATURE METALS

K592

FANSTEEL METALLURGICAL CORPORATION, NORTH CHICAGO, ILLINOIS, U. S. A.

Purity Up . . . Prices DOWN

on Davison mass-produced reactor materials

In less than two years, Davison cuts costs more than 50%
...helps speed economic nuclear power for private industry

TYPICAL ANALYSIS IN PPM

	Enriched Metal	Enriched Oxide
Boron	0.2	0.5
Carbon	100	Negligible
Copper	50	20
Iron	25	100
Nickel	200	55
Nitrogen	75	Negligible
Chromium	5	50
Silica	50	100

Total cross-section of impurities less than equivalents of 5 ppm of boron.

TYPICAL CURRENT PRICES

Depleted Uranium Metal	$ 4.85 per lb.
Depleted Oxide	3.30 per lb.
1.6% Enriched Uranium Metal	5.60 per lb.
1.6% Enriched Uranium Oxide	6.75 per lb.
25% Enriched Metal	65.00 per lb.
Highly Enriched Oxide	100.00 per lb.

For uranium metals and oxides, contact Davison. For a complete line of thorium products, contact Davison. For cold enriched scrap recovery service, contact Davison.

W.R. GRACE & CO.
DAVISON CHEMICAL DIVISION
ERWIN, TENNESSEE

New

L&N Modules for reactor control

These compact, plug-in chassis units keep your reactor under control from start-up to shut-down. Incorporating new concepts of reactor control, L&N Nuclear Modules provide simplified calibration, operation and maintenance — allow checking of components while the reactor is operating. Pulse channels, Logarithmic channels and Linear-servo channels continuously monitor flux at all power levels. And at all times the reactor is under constant surveillance by load-sharing safety channel modules.

Here is a "building-block" approach, so flexible you can augment your control as your requirements change . . . and still maintain a reliable and safe system. This illustrates another example of Leeds & Northrup leadership in the design of instruments and systems for the nuclear industry.

***For more detailed information** on the application of these exceptional components, ask for Data Sheets EN-03(1), (2), (3), and (4). Leeds & Northrup, Nuclear Systems Group, 4936 Stenton Ave., Phila. 44, Pa.*

LEEDS Instruments NORTHRUP Automatic Controls • Furnaces

WHERE THERE'S BUSINESS ACTION THERE'S A BUSINESSPAPER

In any kind of racing—man, beast, or automotive—the "inside track" is the favored position.

Same holds true in the business race. But here the "inside track" means having more information—sounder information, more complete information, more timely information.

The astute businessman—the man on top and the man on the way up—gets that information from the businesspaper he subscribes to in his particular field. He reads for profit, not for pleasure. He searches for facts he needs to make decisions. For fresh ideas. For new methods. For new products he can put to work. He reads, in short, to get the "inside track" against competition.

And he finds much of what he wants and needs in the advertisements in his businesspaper. So, logically, he reads the advertising with the same scrutinizing care he devotes to the editorial pages.

Take a tip from the man on the move who wants to keep his job and his business *moving*—on the "inside track." Subscribe to your businesspaper. Read every issue. Carefully. Thoroughly. Searchingly.

NUCLEONICS

To see the soundness of National Lead Extrudense brick...

Saw it

Lead brick produced by National Lead's extrusion process – forcing the metal through dies in powerful hydraulic presses – are bound to be sound . . . solid lead from end to end, side to side, top to bottom.

Extruded brick have uniformly high density, freedom from voids, clean profile and a glass-smooth surface.

The internal soundness of National Lead's Extrudense lead brick is easy to prove. Sawed through in any direction it will be virtually impossible to find a flaw. As a matter of fact, every brick is sawed, to its six or eight inch length, from the long bar that comes from the extrusion press. (See photographs below).

Extrudense lead brick, curved or flat, for two-inch, four-inch and six-inch protection are regular production items in National Lead's plants. Get in touch with our nearest branch when you want *shielding lead* produced with *National Lead* know-how.

Workman saws off length of Extrudense lead "two-by-four" as it slowly rises through opening in platform at top of extrusion press. This long bar goes to cutting table where . . .

Workman precision saws extrusion into regular-length Extrudense brick. Curved brick are similarly extruded and sawed, then machined to curve ends to provide both more effective shielding and an interlock.

National Lead Shielding

NATIONAL LEAD COMPANY · New York 6; Atlanta 9; Baltimore 3; Depew (N. Y.); Chicago 80; Cincinnati 3; Cleveland 13; Dallas 2; Pittsburgh 12; St. Louis 1; Boston 6 (National Lead Co. of Mass.); Los Angeles 23 (Morris P. Kirk & Son, Inc.); Toronto, Canada (Canada Metal Company, Limited)

Monel alloy counters UF_6 attack on lines and fittings carrying corrosive

Two Inco Nickel Alloys lengthen life of equipment processing nuclear fuels commercially

Mallinckrodt Chemical Works produces reactor fuels of uranium dioxide and other uranium compounds on a commercial basis at Hematite, Missouri. Enrichment of these uranium products ranges from less than 1% U-235 to more than 90%.

The products are derived from UF_6 liquefied gas . . . hydrolyzed, precipitated as ammonium diuranate and dried to produce U_3O_8.

To withstand attack by the highly corrosive UF_4, Monel* nickel-copper alloy lines carry gas from container to hydrolysis.

In further processing, batches of U_3O_8 are fired in cracked ammonia atmospheres at 1500° to make UO_2, suitable for use in pellet fuels. (A sintered material for use in matrix-type fuel elements is also made.)

Inconel* nickel-chromium alloy trays and fixtures successfully endure the severe heat and corrosive atmospheres in the furnace.

Both Inco Nickel Alloys are extensively used for other corrosion- and heat-resisting equipment producing and concentrating uranium and uranium fuel materials. The Development and Research Division of Inco has helped solve many metal problems in this design area. They can probably help with yours . . . if you say the word.

*Registered trademark

THE INTERNATIONAL NICKEL COMPANY, INC.
67 Wall Street — New York 5, N. Y.

Inconel alloy reduces oxidation damage to batch trays and fixtures in 1500°F converting furnaces

INCO NICKEL ALLOYS

NUCLEONICS
ATOMIC POWER
NUCLEAR ENGINEERING
APPLIED RADIATION
APRIL, 1959

Wanted: Nuclear Clipper Ships—Now

"*You are replacing obsolete ships with obsolete ships,*" the veteran ship operator, a hardboiled businessman, told the U. S. Maritime Administrator in the latter's Washington office last year.

And that, indeed, is what the Government's Merchant Ship Replacement Program would appear to be doing. For the current fiscal year, for each of the previous two years, and probably for next year, the Federal ship construction subsidy has amounted to about $130-million/yr, a sum paying up to 50% of the cost for 14 ships a year. Another $130-million/yr goes for operating differential subsidy. Yet these new ships, subsidized though they are, will not be able to meet the competitive challenge of foreign merchant fleets on all trade routes.

Nuclear energy development has already reached the stage today where, even without a single nuclear merchant ship yet in operation, calculations show that a nuclear tanker, because of a 5 to 20% greater carrying capacity, is already on the thin edge of being competitive with conventional tankers. In addition, like central station power plants, it stands to benefit from improved second and later cores. And, although a nuclear ship is not intrinsically faster, the infinitely greater concentration of its power source permits it to operate at top speed all the time, which no oil-burning tanker can afford to do under commercial conditions.

Then, too, the best application for nuclear ships would be in trades where the U. S. flag has been almost entirely driven from the sea because it cannot meet foreign labor costs. Industry people who have had the most to do with designing reactors for immediate maritime application now feel that this use may actually become economic earlier than central-station nuclear power.

But instead of exploiting the vast potential of this new kind of fleet, we are drifting. N. S. *Savannah*, the country's first nuclear merchant ship, is now rising on the stocks at Camden, N. J., to be launched in July or August and ready for sea a year later. Her mission is to provide operating experience and win acceptance for nuclear ships in the world's ports. But there is no authorization nor firm plan to start a near-competitive second ship. Plans to install a reactor in a tanker were blocked by the Administration for budgetary reasons last year and again this year. (A nuclear icebreaker, also voted by Congress last year for its polar-strategy value, was also vetoed.) A development program on an advanced gas-cooled maritime reactor was begun last year, but that will take six more years—to completion only of a land-based prototype.

The research and development data worked up for *Savannah* and in numerous studies on boiling water, organic-moderated and gas-cooled reactors for maritime use has—properly—been unclassified. But the British, the Germans, the Japanese and others are making more use of it than we ourselves. It is ironical that in an industry the U. S. has traditionally protected, we are giving away the one chance that industry has to minimize the handicaps that make protection necessary.

The golden opportunity to put the U. S. in the forefront of the world's maritime nations—as it once was in the heyday of the clipper ship—in spite of the tremendous handicap of higher U. S. costs, is still going begging. The bold plan for a Nuclear Ship Cooperative Program (NU, June '58, 20) along the lines of AEC's Power Demonstration Reactor Program seems to have been abandoned, for this year at least, by a budget-minded Administration; Secretary of Commerce Lewis Strauss curtly brushed off Congress' call for an orderly, long-range program to develop an economic merchant marine. And the second ship is nowhere on the horizon. Even if action were taken this year, a second reactor-driven vessel could not be made ready for sea before 1964—a decade after President Eisenhower first captured imaginations with his call for a nuclear merchant ship.

In the face of Administration apathy, the strongest support for a nuclear fleet comes from Congress—from Chairman Anderson of the Joint Committee on Atomic Energy and Bonner of the House Merchant Marine Committee, and from Senate Majority Leader Lyndon Johnson whose 12-point legislative program singled out nuclear ship development as the most urgent task in the atomic field.

Several responsible ship operators have indicated their willingness to invest in nuclear ship development now, under a cooperative program with the Government.

The Administration has refused to act on either the program or the second ship. It is clearly up to the Congress to launch a U. S. nuclear merchant fleet. The Congress should authorize both the cooperative program and the tanker—this year. —*JEK*

Reactor-Containment Engineering —Our Experience to Date

Thus far eleven U. S. power-reactor containment shells have reached construction. This experience has helped both to mold design practices and to underline needs for energy-release data and greater standardization

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U. S. EXPERIENCE in designing and building reactor containment shells is now sufficiently extensive (see table, p. 88) to make efforts at defining some of the basic principles profitable. For any reactor, work on the containment shell follows the same sequence: estimation of the maximum energy release, selection of vessel size and shape, detailed design of the vessel structure, and erection and testing. Although each reactor presents unique problems in these various phases, resulting in a unique containment design, the overall characteristics of vessel designs (see table, p. 88) have turned out fairly similar. Part of the reason for this uniformity is that vessel designers have usually tried to conform to the ASME Code for Unfired Pressure Vessels.

Present activities aimed at a more basic understanding of energy-release processes and more realistic vessel-code standards are expected to result in lower reactor-containment costs without sacrificing public safety.

Energy Release

The first step in designing a reactor containment vessel is to estimate the total energy release for the "worst credible accident." The potential sources of energy include nuclear releases, chemical reactions between the materials present and the stored thermal energy of the materials within the reactor and primary system.

Release of the stored thermal energy in the coolant or moderator is the easiest to visualize since this would require only a rupture in the reactor vessel or piping system, allowing the coolant to escape. The thermodynamic properties of the coolant may cause it to flash to vapor, giving up part of its energy to the air and producing a rapid increase in pressure inside of the containment shell. This is a very direct action and it is logical to predict that a sizable percentage of stored thermal energy can be transformed into pressure working against the containment shell. The time required for the mechanisms of escape, vaporization and expansion to occur and the absorption of heat by cold surfaces (such as concrete walls and floors) will help to limit the peak pressure. Nevertheless, stored thermal energy can be the most important energy release anticipated in "the worst credible accident" in some reactor systems.

Hence for water-cooled or -moderated systems it is usual to begin by computing the pressure increase from the theoretical instantaneous release of the energy stored in the coolant or moderator, assuming no reduction for heat transfer to other surfaces. The effects of combining this energy release with various combinations of potential nuclear or chemical reactions are then studied. Generally the pressure due to stored thermal energy with no reduction for heat transfer is felt to be quite conservative and the possibility of a combination of the full theoretical energy releases from several sources too remote to be considered at normal design stresses.

For one thing, the conditions required to sustain nuclear or chemical releases are exacting enough so that the realizable energy releases from these sources will most likely always be far below theoretical. For example, it is generally assumed that if a nuclear release occurs it will breach the reactor vessel and surrounding structure but that the containment shell will not experience any shock wave. Also, although little experimental evidence exists, the time lags for the various types of energy to become available are unlikely to coincide (although little experimental evidence exists on this point).

Following this line of reasoning, the design of a containment vessel may be assumed conservative if it considers all of the energy from an instantaneous expansion of the high-pressure, high-temperature coolant to be released into the containment volume as a constant internal-energy mixing process in a closed thermodynamic system. The first law of thermodynamics and the Gibbs-Dalton law for gas mixtures are assumed to apply. Assuming that the contained air in the vessel is dry, the following equations must be satisfied:

$$P = P_a + P_s \frac{460 + T_2}{460 + T_1} \qquad (1)$$

where P = final absolute mixture pressure (psia)

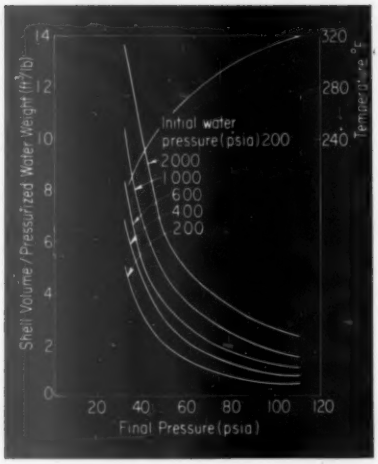


FIG. 1. Containment-volume requirements for water reactors. Volume per unit weight of coolant water is plotted against final containment-volume pressure for various reactor-system design pressures. Curve at upper right relates final pressure and temperature of saturated steam-air mixture for 100° F initial air

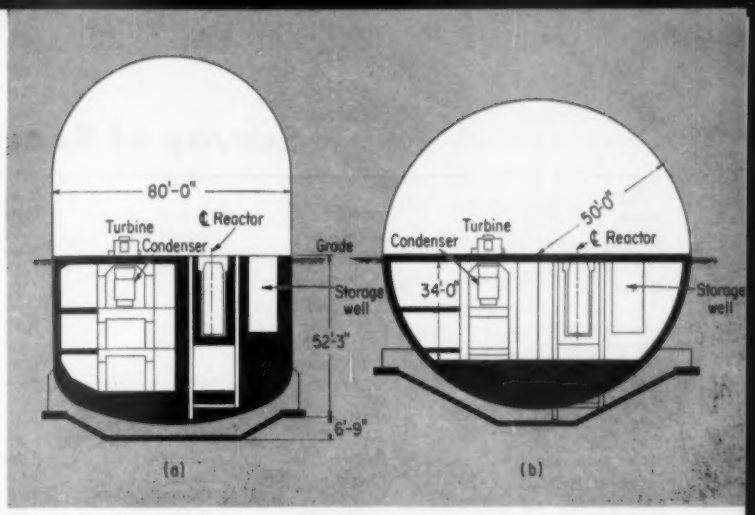


FIG. 2. Equipment arrangement favored cylindrical container (a) over equivalent-volume sphere (b) for EBWR

P_s = saturated steam pressure at T_2 (psia)
P_a = initial air pressure (psia)
T_1 = initial air temperature (° F)
T_2 = equilibrium mixture temperature (° F)

$$W_{a1}\left(U_{a1}+\frac{V_{a1}^2}{2gj}+Z_{a1}\right)+W_w\left(U_{f1}+\frac{V_{w1}^2}{2gj}+Z_{w1}\right)=W_{a2}\left(U_{a2}+\frac{V_{a2}^2}{2gj}+Z_{a2}\right)+(1-x)W_{w1}\left(U_{f2}+\frac{V_{w2}^2}{2gj}+Z_{w2}\right)+xW_{w1}\left(U_{g2}+\frac{V_{w2}^2}{2gj}+Z_{w2}\right) \quad (2)$$

W_a = weight of air (lb)
W_w = weight of water (lb)
V_a = velocity of air (fps)
V_w = velocity of water (fps)
U_a = internal energy of air (Btu/lb)
U_f = internal energy of water (Btu/lb)
U_g = internal energy of steam (Btu/lb)
g = gravitational constant (32.2 ft/sec²)
j = heat equivalent to work (778 ft lb/Btu)
Z = potential energy due to position
x = steam quality (%)
Subscript 1 = initial condition
Subscript 2 = final condition

In most practical instances, the potential-energy term Z and the kinetic energy terms $\frac{V^2}{2gj}$ may be neglected. Thus Equation 2 reduces to

$$W_{a1}U_{a1}+W_{w1}U_{f1}=W_{a2}U_{a2}+(1-x)W_{w1}U_{f2}+W_{w1}U_{g2} \quad (3)$$

When water is present either as coolant or as moderator, these equations can be solved by trial and error for the relationship between (a) the free containment-vessel volume required for each pound of hot water and steam in the reactor system and (b) the equilibrium containment-vessel pressure. This relationship is shown in Fig. 1 for several curves corresponding to different system pressures in a boiling-water reactor. For a pressurized-water reactor the curves used should correspond to the average saturation temperature in the system. The abscissa indicates the pressure in the containment vessel after equilibrium flashing to the volume shown on the ordinate with no heat lost from the thermodynamic system. Note how rapidly the volume must increase as the pressure is reduced.

Representative of the chemical-energy sources that may contribute significantly to containment-vessel loading is the exothermic reaction between zirconium and water. While the exact conditions for starting such a reaction are uncertain, the containment designs for several large-scale plants have included some portion of the theoretical energy available from this source. Usually the formation of crystalline ZrO_2 is assumed according to the equation

$$Zr + 2H_2O \rightarrow ZrO_2 + 2H_2 + 2{,}970 \text{ Btu/lb Zr}$$

If the reaction product is actually fused ZrO_2, the heat of reaction would be only 840 Btu/lb of Zr.

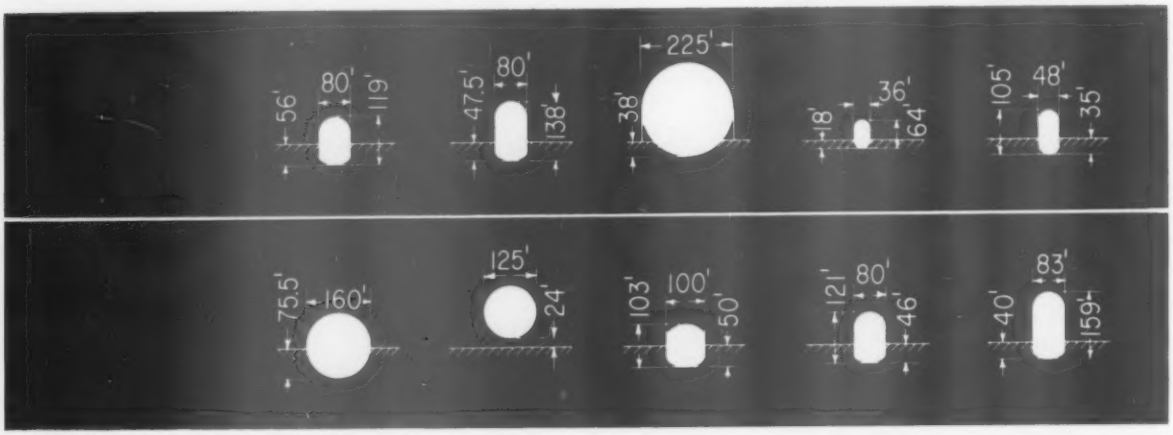
As shown in the above equation, free hydrogen is one of the reaction products. In the presence of elevated temperatures and possibly electrical discharges, the H_2 may build up to a combustible or explosive concentration and add its chemical energy to the container volume. Other possible chemical-energy releases, depending upon system conditions, are

$$U + 2H_2O \rightarrow UO_2 + 2H_2$$
$$U + 3H_2O \rightarrow UO_3 + 3H_2$$
$$3U + 8H_2O \rightarrow U_3O_8 + 8H_2$$

The maximum nuclear-energy release would correspond to fission of the fissionable nuclei present plus the fission-product decay heat. To evaluate the probable nuclear-energy release one follows the nuclear transient resulting from an assumed reactivity change. Such excursions may be limited or stopped by expansion of the fuel, expansion of the moderator or Doppler effects. In any case, energy releases of sufficient magnitude to breach the primary reactor system

Survey of Reactor Containment Vessels

Reactor					
Name:	EBWR	EBR-2	SIR-A	APPR-1	VBWR
Type:	boiling-water	fast-breeder	sodium-cooled	pressurized-water	boiling-water
Location:	Lemont, Ill.	NRTS, Idaho	West Milton, N. Y.	Ft. Belvoir, Va.	Pleasanton, Calif.
Owner:	AEC	AEC	AEC	USA	GE
Prime contractor:	ANL	ANL	KAPL	Alco	GE
Thermal output:	20 Mw	62.5 Mw	n.a.	10 Mw	30 Mw
Fuel:	U-Zr	U metal	U metal	UO_2	UO_2
Cladding:	Zircaloy-2	stainless	stainless	stainless	stainless
Operating temperature:	488° F	900° F	n.a.	450° F	545° F
Operating pressure:	600 psig	~100 psig	n.a.	1,200 psia	1,000 psig
Containment-vessel					
Gross volume:	497,500 ft³	~595,000 ft³	6,000,000 ft³	52,700 ft³	~160,000 ft³
Design pressure:	15 psig	24 psig	20 psig	66.3 psig	45 psig
Test pressure:	18.75 psig	30 psig	25 psig	75 psig	56 psig
Plate material:	A201 (A300)	A201	A201 (A300)	SA212	SA212
Plate thickness:	0.375, 0.625 in.	0.5, 1 in.	0.9, 1.1 in.	0.875 in.	0.436, 0.875 in.
Specified leakage:	0.25 %	0.2 %	0.5 %	0.76 %	1.0 %
Year built:	1955	1958	1953	1956	1956
Built by:	Graver	Graver	CB&I	Bethlehem Steel	Consolidated Western Steel



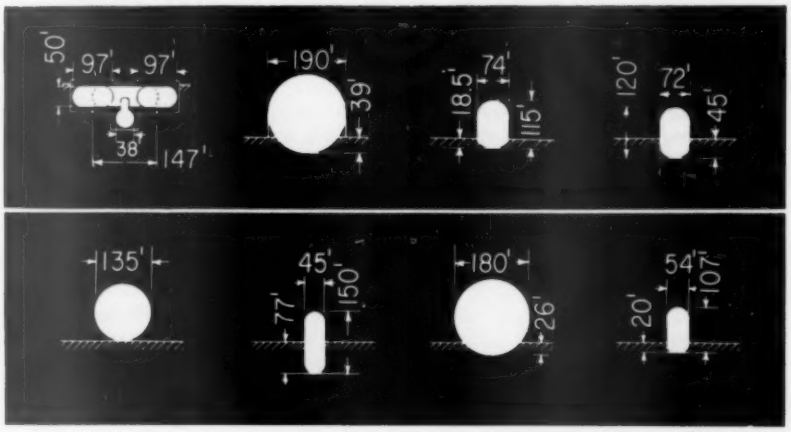
Reactor					
Name:	Indian Point	Yankee	NASATR	PRTR	AFNETR
Type:	pressurized-water	pressurized-water	tank	tank	tank
Location:	Indian Point, N. Y.	Rowe, Mass.	Sandusky, Ohio	Richland, Wash.	Dayton, Ohio
Owner:	Consolidated Edison	Yankee	NASA	AEC	USAF
Prime contractor:	B&W/Vitro‡	Westinghouse	NASA	HAPO	Maxon/ACF
Thermal output:	585 Mw	392 Mw	60 Mw	70 Mw	10 Mw
Fuel:	UO_2-ThO_2	UO_2	U-Al	Pu-Al, UO_2	U-Al
Cladding:	Zircaloy-2	stainless	aluminum	Zircaloy-2	aluminum
Operating temperature:	510° F	550° F	187° F	530° F	137° F
Operating pressure:	1,500 psig	2,000 psia	135 psig	—	—
Containment-vessel					
Gross volume:	2,140,000 ft³	1,020,000 ft³	520,500 ft³	504,500 ft³	739,000 ft³
Design pressure:	25 psig	34.5 psig	5 psig	15 psig	12.8 psig
Test pressure:	31.25 psig	43 psig	—	18.75 psig	16 psig
Plate material:	A201 (A300)	A201 (A300)	A285-54T	A201 (A300)	A201 (A300)
Plate thickness:	0.89, 1.03 in.	0.875, 1.25 in.	0.750 in.	0.375, 0.625 in.	0.563, 1 in.
Specified leakage:	0.1 %	0.1 %§	0.3 %	0.2 %	0.1 %
Year built:	under constr.	under constr.	1958	under constr.	1958
Built by:	CB&I	CB&I	Hammond Iron Works	J. P. Hopkins	CB&I

Explanatory Notes

Plate material—ASTM designations; designation in parentheses is heat treatment.
Plate thickness—of two numbers, first is thickness of heads, second is thickness of wall; where only one number is given, it is for wall.
Specified leakage—leakage in percent contained atmosphere in 24 hr at design pressure (except as noted).
n.a.—not available.
ACF—ACF Industries, Inc.
AEG—Allgemeine Elektrizit Aäts-Gesellschaft
AFNETR—Air Force Nuclear Engineering Test Reactor
Alco—Alco Products, Inc.
ANL—Argonne National Laboratory (operated by Univ. of Chicago for AEC)
APPR-1—Army Package Power Reactor
BR-3—Belgian Reactor
B&W—The Babcock & Wilcox Co.
CB&I—Chicago Bridge & Iron Co.
CEN—Centre d'Etudes Nucléaires
Cockerill—Société Anonyme Cockerill-Ougrée
EBR-2—Experimental Breeder Reactor
EBWR—Experimental Boiling Water Reactor
EDF—Electricité de France
GE—General Electric Co.
Graver—Graver Tank & Mfg Co., Inc.
HAPO—Hanford Atomic Products Operation (operated by General Electric Co. for AEC)
KAPL—Knolls Atomic Power Laboratory (operated by General Electric Co. for AEC)
Maxon—Maxon Construction Co.
Motherwell—Motherwell Bridge & Engineering Co., Ltd.
NASATR—National Aeronautics and Space Administration Test Reactor
NRTS—National Reactor Testing Station

in the U. S. and Abroad

Shippingport	Dresden	Elk River	Enrico Fermi
pressurized-water	boiling-water	boiling-water	fast-breeder
Shippingport, Pa.	Morris, Ill.	Elk River, Minn.	Lagoona Beach, Mich.
AEC	Commonwealth Edison	AEC	PRDC
Westinghouse	GE	ACF	PRDC
231 Mw	626 Mw	73 Mw	300 Mw
UO_2	UO_2	UO_2-ThO_2	U-Mo
Zircaloy-2	Zircaloy-2	stainless	stainless
538.8° F	547° F	540° F	800° F
2,000 psia	1,000 psig	900 psig	92 psia
600,000 ft³	3,600,000 ft³	405,200 ft³	415,800 ft³
52.8 psig	29.5 psig	21 psig	32 psig
70 psig	37 psig	26.25 psig	40 psig
A201 (A300)	A201 (A300)	A201 (A300)	A201 (A300)
0.75 in.*	1.25, 1.4 in.	0.70, 0.50 in.	1.03, 1.25 in.
0.66,† 1.25 in.			
0.10 %	0.5 %	0.1 %	0.11 %
1956	1958	under constr.	1957
Pittsburgh-Des Moines Steel	CB&I	CB&I	CB&I



Dounreay	Kahl	EDF-1	BR-3
fast-breeder	boiling-water	gas-cooled	pressurized-water
Dounreay, Scotland	Kahl am Main, Germany	Chinon, France	Mol, Belgium
UKAEA	RWE	EDF	CEN
UKAEA	AEG	EDF	Westinghouse
60 Mw	62 Mw	300 Mw	43 Mw
U metal	UO_2	U metal	UO_2
niobium	Zircaloy-2	Mg alloy	stainless
~662° F	~530° F	673° F	515° F
50 psi	650 psig	355.5 psi	2,000 psia
1,290,000 ft³	215,000 ft³	~3,086,100 ft³	215,500 ft³
18 psig		24.2 psi	45 psig
20 psig			56.25 psig
			A201 (A300)
1, 1.875 in.	0.827 in.	0.787, 1.142 in.	0.562, 1.125 in.
			0.1 %
1956	1959	under constr.	1959
Motherwell	AEG	Compagnie Francaise d'Enterprises	Cockerill

PRDC—Power Reactor Development Co.
PRTR—Plutonium Recycle Test Reactor
RWE—Rheinisch-Westfälisches Elektrizitätswerk
SIR-A—Submarine Intermediate Reactor-Mark A
UKAEA—United Kingdom Atomic Energy authority
USA—U. S. Army
USAF—U. S. Air Force
VBWR—Vallecitos Boiling Water Reactor
Vitro—Vitro Engineering Co. Div., Vitro Corp. of America
Westinghouse—Westinghouse Electric Corp.
Yankee—Yankee Atomic Electric Co.

Footnotes

* Mounted on top of reactor-containing sphere is 18-ft-dia × 20-ft cylinder with hemispherical top head that covers control-rod drive mechanisms; plate thickness is 1.25 in. plus 0.5-in. liner.

† Two smaller cylindrical vessels have 1-in. plate for heads nearest sphere.

‡ B&W has contract for R&D and nuclear engineering and is major supplier for reactor and primary-coolant system. Vitro is consultant to Con Ed for reactor and primary-coolant system.

§ At 15 psig.

must be evaluated in establishing the containment-vessel design criteria.

Vessel Size and Shape

Once energy-release estimates have set the design criteria, selection of the vessel size and shape can proceed. This involves a number of different factors and is largely a function of the individual installation.

Included among the considerations is the arrangement of equipment within the containment vessel. The operating floor requirements at various elevations throughout the plant have an important bearing on the selection of the shape of the vessel. A spherical vessel gives a large area near the equator but considerably less floor area at the lower elevations. In contrast, an upright circular cylinder yields a more uniform cross section for all floor elevations. Thus, if the operating-area requirements at lower elevations are nearly the same as those at the main floor, a cylindrical vessel is preferable to a sphere. For example, with EBWR, the equipment arrangement required a distance between the main floor and the basement of 48 ft, with an additional 8 ft to accommodate a part of the reactor foundation. The equipment arrangement also dictated a basement area nearly equal to that of the main floor. To meet these requirements, a cylindrical vessel with an 80 ft i.d. was selected in preference to a 100-ft-i.d. spherical vessel which had essentially the equivalent volume (see Fig. 2).

An analysis of the maintenance operations to be performed within the containment vessel is also necessary at this time to provide sufficient laydown space for equipment. Too small a vessel could make disassembly of equipment very difficult.

Another consideration is the different stress-relieving requirements resulting from the varying plate thicknesses used in the different vessel sizes and shapes. The vessel designer should try to ease the rather difficult erection problems that arise in performing field stress-relief operations on containment-vessel welds. It is most often desirable to keep vessel wall thicknesses small enough not to require stress relief for field welds. The present code allows wall thicknesses up to 1½ in. of SA-201 material without the stress-relief requirements for this type of service. Figure 3 indicates the allowable pres-

sure versus diameter for cylindrical and spherical vessels that can be fabricated without stress relief.

Structural Design

Once the vessel size and shape have been established, the structural design can begin. All of the major containment vessels that have been built in the United States have been designed in general accordance with the ASME Boiler and Pressure Vessel Code, Section VIII, Unfired Pressure Vessels.

A problem in structural design is to provide penetrations in the vessel for personnel, materials, supplies, piping, and wiring without impairing the vessel integrity. If the plant operating procedures allow personnel within the vessel while the unit is operating, the design must include an air-lock arrangement. The two sets of doors should be interlocked so that only one set can be open at any given time. To cover the possibility of an emergency arising when one of the air-lock doors is open, it is a good idea to have a second set of air locks for use during emergency conditions only.

Generally speaking, the air-lock designs have fallen into two categories: those designed for a relatively low pressure differential which use an inflatable seal, and those for high pressure differentials which depend on a compressing force for sealing action. Although the size of these doors varies considerably, a 3–6 ft by 7–8 ft door is typical for personnel air locks. These air locks are exceedingly expensive. A small air lock providing ordinary access for the passage of a few men and using hand-operated door-closing mechanisms may cost from $30,000 to $50,000. This represents a sizeable addition to the containment cost and any alternative schemes to reduce this cost would be of great interest to the nuclear-power industry.

Openings larger than those mentioned become quite expensive for high-pressure installations, although air locks of about 10 ft by 12 ft have been built for truck access in low-pressure installations. As complications are added, either in the door-operating mechanisms or in the size of the door openings, the cost could increase to several hundred thousand dollars. In several instances, a bolted and gasketed door has been used to move equipment in and out when the plant is shut down.

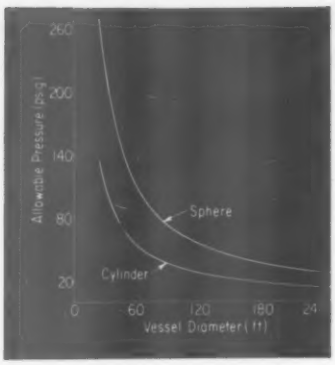


FIG. 3. Containment vessels lying below the curves may be fabricated without stress relief (assumes SA 201 Gr. B 1.5-in. wall)

For high-pressure installations, a large material-handling opening of this type is much less expensive than large air locks.

Numerous variations in design may be used for the piping and wiring penetrations. While ordinary piping penetrations do not in general present too serious a problem, wiring penetrations are somewhat more complicated. Leakage may occur between the cable and the vessel wall, through stranded conductors, and through the space between the cable and its insulation. Some designs have used conduit- and pressure-type fittings for each individual wire or cable passing through the vessel. For a large power reactor, this design leads to a large number of individual penetrations. A more economical solution uses multiconductor cable with a special filler material and a special bond between the filler and insulation material. Solid conductors for cables of No. 6 size and smaller will prevent leakage through the conductor. Where stranded conductors are necessary, the strands may be adequately sealed at both ends of the cable by filling with solder.

The Elk River design proposes to use two compression-type fittings in series for each multiconductor cable.

In this instance, the cable penetrations will be located in a double-walled section of the containment vessel to permit testing of the chamber for seal leaks at any time after erection under either pressure or vacuum.

In an alternative arrangement, a cable pass-through design has used a "U" section of a cable pan welded to the vessel wall and filled with a compound

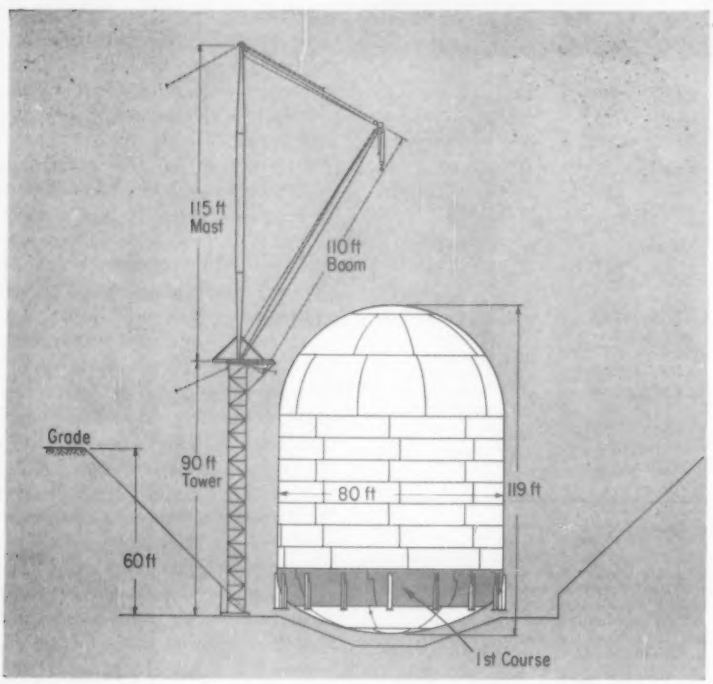


FIG. 4. Typical plate pattern for containment shell. Shaded belt is erected first

that hardens to form a seal between the cable insulation and the walls of the well. Spare gastight individual conduit sleeves allow replacement or addition of cables after the installation is completed. With containment vessels designed for relatively low pressures, liquid seals may be used to advantage; these allow the greatest flexibility in design and in cable replacement or addition.

In several instances, the containment design has called for a large water supply that could be introduced into the containment vessel as an emergency measure to absorb an energy release. The mechanism should be independent of an external power source. An economical solution is to incorporate an overhead storage tank at the top of the containment vessel. Thus the containment vessel itself serves as the support for the tank and helps give the water supply sufficient head to overcome the pressure expected within the vessel following an accident. (For example, with a vessel designed for 25 psig, an external water tank should be about 60 ft above the top of the containment vessel.)

In choosing proper steels for the design, every effort should be made to avoid steels that are particularly susceptible to brittle failure. Most of the containment vessels designed to date have utilized SA-201 Grade B steels conforming to ASTM Specification A-300; the latter specifies heat treatment to normalize the grain structure and Charpy tests to determine resistance to impact loadings at low temperatures. A recent interpretation of the ASME Unfired Pressure Vessel Code has made the SA-300 specification mandatory for containment vessels bearing the code stamp.

The importance of protecting against embrittlement cannot be overemphasized. Since the Charpy tests commonly used to measure resistance to embrittlement depend upon the use of impact loading, it is easy to fall into the erroneous assumption that brittle failures occur only under a shock loading. However, most pressure-vessel brittle failures occur under static loadings rather than under impact loadings. The susceptibility to brittle failure is increased by surface discontinuities, points of restraint (such as the bottom of a vessel resisting the expansion or contraction of the sides), overlaps of weld metals, notch conditions, or other conditions tending to set up a concentration of stresses. These problems are probably more severe in containment vessels than in many other types of pressure vessels because of the complications added by the remaining structures in a nuclear plant.

Why Not Use Prestressed Concrete Shells?

For conventional structures, prestressed concrete often costs less than steel. This may also be true for containment vessels, especially those that use shadow shielding or a biological-shield lining. As far as serviceability goes, prestressed vessels have already proved themselves reliable as water tanks, petroleum storage tanks and chemical processing vessels. The French, who have more experience with prestressed structures than U. S. engineers, are using concrete pressure vessels for their gas-cooled G-1 and G-2 plants.

One American firm, the Preload Co., New York, which has had experience with prestressed concrete, estimates that the use of this material could save up to 10–15% of present U. S. containment-shell costs. The typical shell would be a vertical concrete cylinder prestressed both vertically and horizontally during construction so that the concrete stress would be zero when the shell is loaded at the maximum design pressure. The top of the cylinder would be capped by a steel hemisphere and the bottom sealed to a concrete floor. Circumferential prestressing is applied by wrapping wire around the cylinder and stressing it to approximately 150,000 psi; this places the concrete under a compressive stress of about 2,000 psi. Vertical prestressing is applied by wires or bars embedded in small metal sleeves within the concrete wall and anchored to the floor slab and roof at either end. Jacks are used to prestress these elements prior to anchoring the upper extremities.

On the debit side, the prestressed-concrete approach, because it involves materials in a permanent state of high compression, assumes a completely new concept of allowable stress distributions. Also, anchoring the head to the cylinder (which may involve forces as high as 18,000 lb/linear in. of circumference) may present problems.

Erection

The erection procedures for containment vessels are, in general, similar to those for any large-scale vessel. Erection usually starts with the placing of steel columns which are then joined by and support the first complete belt of plates. Once this belt course is completed, erection proceeds below and above the belt, using it for support. A sketch of the erection of a containment vessel by this procedure is shown in Fig. 4. Field welding follows as each course is erected and much of this can be done by automatic welding machines.

Procedures for testing the adequacy of construction greatly affect construction operations. Ordinarily specifications demand that joints in the plates shall be double-butt welds and shall be accessible from both sides during testing. The vessel is then completed, pressurized to some fraction of the design pressure, and all joints tested for leakage by soap bubble or other tests. Next, the air pressure test is applied as prescribed in the Unfired Pressure Vessel Code to bring the internal pressure up to 1.25 times the design pressure. After the structure proves itself at this pressure, the pressure is reduced to the design pressure and held at this point. Attempts are then made to measure the leakage, which should not exceed approximately 0.1% of the contained volume per day.

The code requirements for such containment vessels also call for all welds to be radiographed. This means that both sides of the entire surface of the shell must be accessible. To provide an inspection space below the bottom of the shell, temporary supports for the shell are required during construction and inspection operations. Following completion of the inspection and testing, the space below the shell is usually filled in some manner to transmit the structural and equipment loads to the soil or foundation below. A large construction opening is then cut through the side of the shell and all

interior construction operations are handled through this opening. This increases the difficulty of concreting operations within the shell and the erection of equipment inside the shell, as all material and equipment must be brought through this opening and, in many cases, the use of cranes in the interior is seriously hampered. The added cost of these difficulties is difficult to estimate for either the engineer or the contractor, but they are obviously a major cause of high construction costs in nuclear plants. An indication of the close quarters for rigging and handling large pieces of equipment under these conditions is illustrated in Fig. 5.

A recent ruling* of the ASME Boiler and Pressure Code relative to nuclear installation points out a way to reduce difficulties. The ruling says that the lower part of a containment vessel can be constructed and covered so that the welds will not be available for inspection at a later testing date provided that all welds are double-butt welded, radiographed, and fully inspected and tested for leaktightness by means such as Halide leak-tests.

* Case No. 1228, December, 1956.

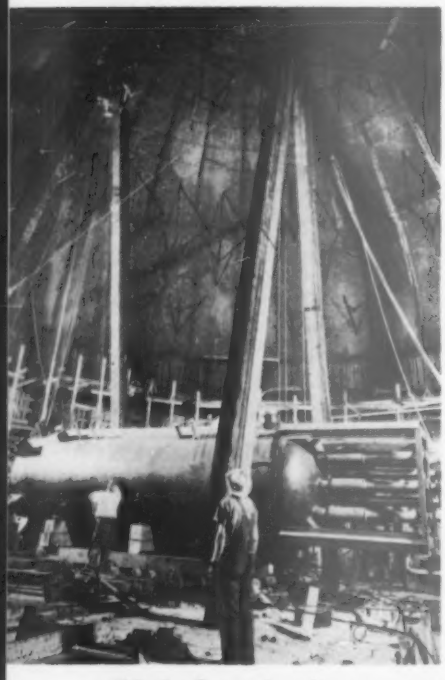


FIG. 5. Cramped working space was result of original rule that containment shell be completed before plant equipment could be brought in

ASME Pressure-Vessel Code Rulings for Containment Vessels

Case No.	Rulings
1218	Identification data may be stenciled instead of die stamped.
1224	Delineates provisions for ASME Code stamping of vessels built as an integral part of a nuclear installation.
1224-1	Defines containment vessels, primary vessels and reactor vessels.
1226	Containment vessels may be built without stress relief if: a. Plates and forgings exposed to the elements conform to specifications SA-300 and SA-350 respectively and meet certain requirements. b. Welding procedures and operators are qualified in accordance with the Code. c. Shell and head plate thickness do not exceed values for which stress relief is required.
1226-1	Stress relief is not required for thicknesses between 1.25 in. and 1.50 in. provided a preheat of 200° F is used during welding for materials under group P-1 in table USC-23 of the Code.
1226-2	Definition of containment vessel.
1226-3	Mandatory corrosion allowances of paragraph UG-25 are not intended to apply to containment vessels.
1228	Inspection of joints may be waived in a 2-stage construction program if: a. Joints and plates containing no penetrations are covered by concrete. b. All inaccessible welds are double-butt welded, radiographed, fully inspected and tested for leaktightness with a gas medium such as a Halide leak detector prior to being covered with concrete. c. All other Code requirements are met, including a complete pneumatic test of the completed vessel.
1235	Containment vessels need not be furnished with pressure-relief valves.

Hence the lower portion of the shell could be welded, inspected, and then lowered into a prepared footing, or else the space below filled in. The construction of the internal works could then proceed in the open with full access for cranes and other equipment. When convenient, the upper part of the shell could be constructed to complete the containment vessel and then pressure tested using the procedures previously discussed. This procedure would mean that nuclear plants could be built in a manner comparable to modern construction practices instead of threading the entire plant through the eye of a needle.

Vessel Standardization

The table (p. 88) summarizes the containment-vessel design data for all the power reactors in the U. S. plus representative examples for other reactor types. In examining the various arrangements one should bear in mind that they were developed without a specific set of ground rules to guide the designers. Even so there are many striking similarities between the various installations. The detailed designs have generally followed the ASME Code for Unfired Pressure Vessels and special rulings (see box) issued by the Code Committee since containment vessels began to be built. A movement is underway by the American Standards Association, sponsored jointly by the American Nuclear Society and the American Society of Mechanical Engineers, to establish safety standards for reactors, but this may possibly take a long time to develop. Installations that have been completed will certainly influence the future standards, since they actually represent a fair cross section of the opinions of people now engaged in nuclear-plant design.

Since containment structures appear to be a factor in design for some years

to come, the standardization of design criteria for these structures deserves considerable thought. The assumptions used to establish the original design criteria vary considerably and lead to large differences in the complexity and cost of the final design. A great deal of confusion and expense could be eliminated if a proper set of ground rules for determining these design criteria could be established. Even though appearance of the final designs may differ, a uniform set of design criteria should be established that can be enforced consistently throughout the country, since there should be no variation permitted except as might be logical in differentiating between populated and unpopulated areas.

The present Section VIII of the ASME Boiler and Pressure Vessel Code, Unfired Pressure Vessels, is an excellent but extensive specification designed to cover a broad spectrum of vessel types. It is prepared primarily for the design of vessels subject to constant or frequent loading and, as such, is based on extremely conservative values for allowable stresses and other design criteria. So far, containment vessels have been designed for an assumed static-pressure condition in much the same manner as a large water tank is designed for a load it carries constantly; little consideration has been given to the fact that the loading condition on the shell may never be wholly achieved. The necessity for designing for the "once-in-a-lifetime" load on the same basis as the "always present" load should be given serious consideration. Allowable stresses for the latter loading conditions must naturally include factors such as fatigue or creep or embrittlement due to cold working that need not be considered to the same extent on containment vessels.

As plants become larger, they are approaching the point where the large containment vessels cannot meet the limitations shown in Fig. 3. This means that either the allowable stress must be increased or field stress relieving will be a necessity. One can argue that the serious consequences of a possible failure rule out any increase in allowable stress. On the other hand if the stresses are properly calculated, the safety factor of 4 presently used seems extremely high for this load, which might never be encountered; a factor of safety of 3.5 or 3 might be just as logical and would save steel.

One point, however, that tends to work against the argument for increasing Section VIII allowable stresses is that the code is based primarily on vessels in which the openings through the shell are quite small. As yet, no extension of code has been made to cover openings of the sizes encountered in nuclear-containment vessels. Hence a real danger exists in blindly applying the code formulae to containment vessels with large openings, and the use of the conservative allowable stresses is not in itself foolproof.

Another reason for keeping factors of safety relatively high is that design formulae given in the code do not take into account the higher localized stresses at discontinuities in the surface. An example is the stress-concentration zone at the junction of a cylinder and its head where the stress may be higher than the stress in the main portion of the cylinder. Thus, the use of the code-design stresses actually puts extra steel at points of almost pure membrane stresses to keep the vital areas of stress concentrations from being over stressed.

In addition to the questions about the structural design of these vessels, serious thought should also be given to the criteria on which the design is based. In most instances, additional work is being done to reach a more thorough understanding of the mechanisms by which the various potential energies present can be released to load the containment vessel. Notable among these are continuing studies of what chemical- and nuclear-energy releases are possible and plausible. An area of concern that could have marked influence on containment-structure cost is the heat loss to cold surfaces within the containment structure. In many cases this heat-sink effect is recognized as being present and is thought of as an additional safety factor in the design concept. The magnitude of this unevaluated safety factor may vary between 1.3 and 2, depending upon the thermal diffusivity and heat capacity of the materials exposed to the incident.

Why Not Put Reactors Underground?

An intriguing alternative to building huge reactor containment shells is to contain the reactor underground in an excavation in a suitable rock stratum. Besides eliminating the costly above-ground shell, underground containment would require little maintenance work and would, of course, be insensitive to weather phenomena.

An AEC study report,* however, concludes that for present-day reactor sizes the cost of rock excavation makes underground containment more costly than the current methods. The study considers a hypothetical excavation in rock for EBWR lined with 1–2 ft of concrete plus a light gage metal. The total cost of the underground scheme would be $940,000 compared with an actual EBWR containment cost of $665,000. The difference amounts to about 7% of the total plant cost. Besides its economic problems underground installation has these disadvantages:

- **Difficulty of determining the exact conditions of the rock structure in advance.**
- **A slight possibility of contaminating ground water in event of an incident.**
- **Limited flexibility for access and expansion.**

Since excavation costs decrease with size, underground containment may eventually prove economic for fairly large nuclear plants. Some argue that even before this happens the cost penalty incurred by underground containment could well be subsidized by the government to help provide a network of underground power sources safe from enemy attack.

* Christian Beck, Engineering study on underground construction of nuclear power reactors, AECU-3779 (April 1958)

BIBLIOGRAPHY

1. Alf Kolflat, W. A. Chittenden. A new approach to the design of containment shells for atomic power plants, *Proc. Am. Power Conf.* **19**, (1957)
2. Alf Kolflat. Review of present American design of containment vessels for nuclear power plants, Meeting of the Internat. Org. for Standardization at Harrogate, England, June 1958
3. R. N. Bergstrom, Containment of nuclear plants, ASCE Convention, October 1958

NUCLEONICS Previews Cleveland—

1959 Nuclear Congress and

Highlights of 1959 Nuclear Congress

What	*When*	*Where*	*Who*	*How much*
AtomFair	Mon., Apr. 6—Fri., Apr. 10	Public Auditorium	>140 exhibitors (see next page)	$2.00*
5th Nuclear Engineering & Science Conference	Mon., Apr. 6—Thu., Apr. 9	" "	24 technical sessions (see below)	$15.00
7th Hot Laboratories & Equipment Conference	Tue., Apr. 7—Thu., Apr. 9	" "	8 technical sessions (see below)	$20.00†
AIChE luncheon	Tue., Apr. 7 (12:00 noon)	Hotel Sheraton-Cleveland	Arthur Compton, *Washington University*	$4.25
HL&EC social hour	Tue., Apr. 7 (5:00 pm)	Hotel Statler Hilton	—	dutch
7th Atomic Energy Management Conference	Wed., Apr. 8—Fri., Apr. 10	Public Auditorium	9 panels sessions (see below)	$7–$35‡
ASME-AIEE luncheon	Wed., Apr. 8 (12:00 noon)	Manger Hotel	to be announced	$3.25
ASEE luncheon	Wed., Apr. 8 (12:00 noon)	Hotel Auditorium	John H. Roberson, *Associated Midwest Universities, Inc.*	$3.75
AEMC luncheon	Wed., Apr. 8 (12:00 noon)	Hotel Statler-Hilton	—	$6.00
All-Congress social hour	Wed., Apr. 8 (6:00 pm)	Hotel Sheraton-Cleveland	—	dutch
All-Congress banquet	Wed., Apr. 8 (7:00 pm)	" " "	Herbert F. York, *Dept. of Defense*	$12.00
ANS luncheon	Thu., Apr. 9 (12:00 noon)	" " "	Miles Leverett, *General Electric Co.*	$3.75
AEMC luncheon	Fri., Apr. 10 (12:00 noon)	Hotel Statler-Hilton	to be announced	$6.00

* Registration fee for any of the three conferences includes admission fee to AtomFair. † Includes copy of conference proceedings. ‡ Each panel session will be $7; special full-conference price of $49 includes any five sessions, both luncheons and All-Conference banquet.

Conference Programs at a Glance

Nuclear Engineering & Science

	Session	*Subject*	*Time*
Monday	I	Waste Disposal	9:30 am
	II	Nuclear Research, Test and Training Facilities	9:30 am
	III	Simulation and Experimental Instrumentation	9:30 am
	IV	Water Supply	2:15 pm
	V	Nuclear Instruments	2:15 pm
	VI	Reactor-Component Design	2:15 pm
Tuesday	VII	Health Physics	9:00 am
	VIII	Heat Transfer	9:00 am
	IX	Reactor Instrumentation	9:00 am
	X	Chemistry and Chemical Processing	2:15 pm
	XI	Power-Reactor Design	2:15 pm
	XII	Instrumentation	2:15 pm
Wednesday	XIV	Nuclear Fuel Processing Plants	9:00 am
	XV	Radiotracers in the Process Industries	9:00 am
	XVI	Reactor Physics	9:00 am
	XVII	Fuel Technology	2:15 pm
	XVIII	Isotope Application	2:15 pm
	XIII-A	European Power Reactors	2:15 pm
Thursday	XIX	Fusion Processes	9:00 am
	XX	Metallurgy and Materials—I	9:00 am
	XIII-B	European Power Reactors (French)	9:00 am
	XXI	Metallurgy and Materials—II	2:15 pm
	XXII	Reactor Operation and Maintenance	2:15 pm
	XIII-C	European Power Reactors (Russian)	2:15 pm

Hot Laboratories & Equipment

Session	*Subject*	*Time*
I	Hot Laboratories and Facilities—I	10:00 am
II	Hot Laboratories and Facilities—II	2:00 pm
III	General Manipulative Equipment	8:45 am
IV	Cell Fixtures and Specialized Manipulators	10:40 am
V	Problems in Simultaneous Handling of Alpha- and Gamma-Emitting Materials	2:00 pm
VI	Gamma Irradiation Facilities	8:45 am
VII	Operations and Techniques	10:45 am
VIII	Operational Problems (panel discussion)	2:00 pm

Atomic Energy Management

Session	*Subject*	*Time*
A	Euratom—Sales Opportunities and Obstacles	9:30 am
B	Where is the Profit in Radioisotope Utilization?	9:30 am
D	A Report on the AEC Large-Scale-Reactor Study Program	2:30 pm
E	Potential Applications of Nuclear Weapons for Peaceful Uses	2:30 pm
G	Latest Prospects for a More Economic Fuel Cycle	9:30 am
H	Health and Safety	9:30 am
I	The U. S. Power-Reactor Program—Is Revision Indicated?	2:30 pm
J	What is the Commercial Future of Radiation?	2:30 pm
Friday		
K	International Developments in Atomic Energy	9:3′ am

AtomFair

CLEVELAND, site of the first Nuclear Congress, again plays host to the nuclear industry. Sponsored by 31 engineering, scientific and management organizations, it is estimated that the Congress will draw 4,000 to 5,000 members plus representatives from industrial organizations. The AtomFair, an integral part of the Congress, will be the only major exhibit of nuclear products, materials and services held in the U. S. during 1959. Running concurrently with the AtomFair are three technical conferences. Some 250 original papers on latest developments will be presented by authorities from industry, government and education. All of the conferences and the exhibit will be housed in the spacious Cleveland Public Auditorium, which is located within walking distance of downtown hotels. Tables at the left give the highlights of the 1959 Nuclear Congress and show the conference program at a glance. Below are listed all AtomFair exhibitors available as NUCLEONICS went to press. Numbers in parenthesis are Public Auditorium booths.

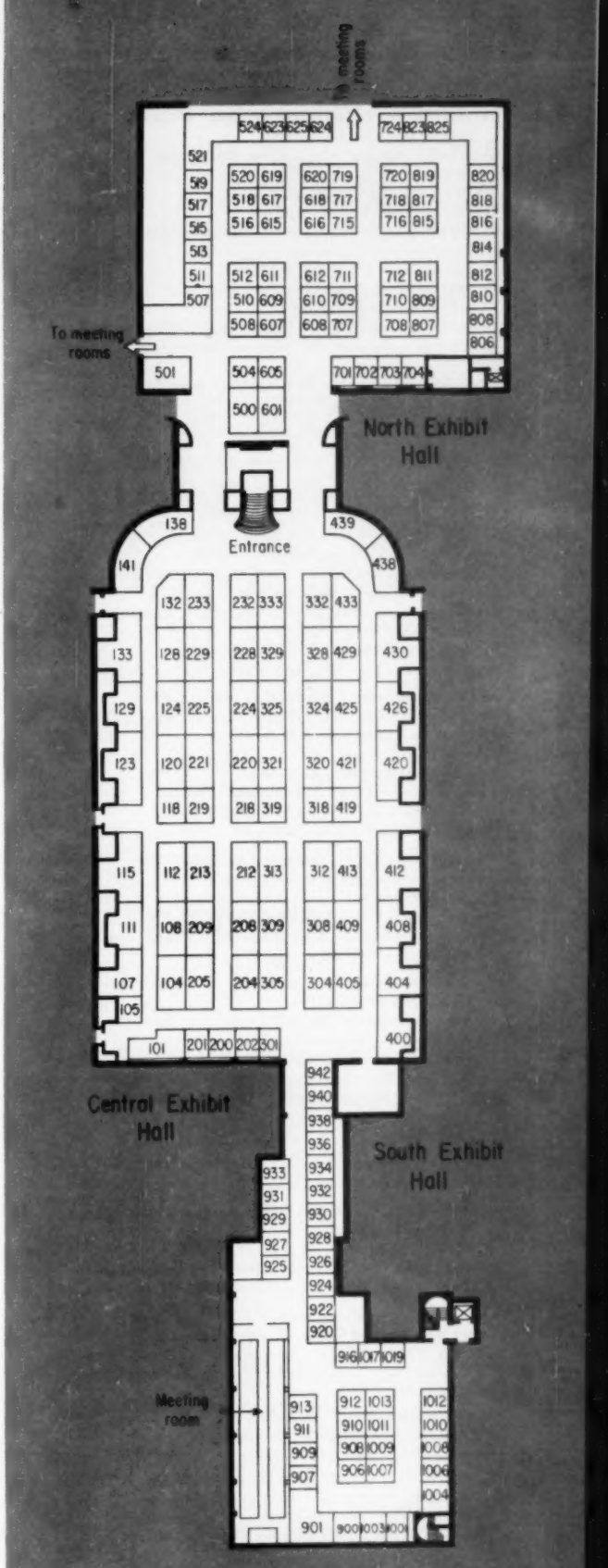
AtomFair Directory

ACF Industries, Inc., Nuclear Products-Erco Div. (715, 717, 719)
Aeroquip Corp., Marman Div. (708)
Alco Products, Inc. Control-rod-drive systems, fuel-element-handling equipment, heat exchangers, pressure vessels, reactors, valves. (810, 812, 814)
Allis-Chalmers Mfg. Co. Betatrons, control rods, ion-exchange equipment, pumps, reactors, steam turbines, thermonuclear equipment. (308)
AMF Atomics Canada, Ltd. Fuel elements. (420)
American Lava Corp. Fuel elements and ceramic materials. (605)
American Machine & Foundry Co., AMF Atomics Div. Control rods and drive systems, fuel elements and handling equipment, manipulators, reactors, thickness gages. (120)
Assembly Products, Inc. Counting-rate and period meters, radioactivity monitors. (609, 611)
Atom Industry. (523)
L'Association Technique de l'Energie Nucleaire. (822, 823, 825)
Atomic Energy of Canada, Ltd. Irradiators, isotopes, radiographic equipment, shielding, shielded containers. (430, 438)
Atomic Industrial Forum, Inc. (504)
Atomics International Div., North American Aviation, Inc. Reactors. (212, 313)
Automatic Switch Co. Process instrumentation. (328)
Autonetics. (329)

The Babcock & Wilcox Co. Fuel elements, heat exchangers, pressure vessels, reactors. (515, 517, 519)
Baird-Atomic, Inc. Nuclear instrumentation. (107)
Bendix Aviation Corp. Nuclear instrumentation. (405, 409)
The Beryllium Corp. (205)
Blaw-Knox Co. Entrainment separators, steam and air traps, pressure vessels, reactors, waste-disposal systems. (200, 201)
S. Blickman, Inc. Fume hoods, glove boxes. (332)
Byron-Jackson Div., Borg-Warner Corp. Pumps, remote handling equipment. (123)
The Brush Beryllium Co. (623, 625)
The Bureau of National Affairs, Inc. (704)
Burroughs Corp., ElectroData Div. (820)

Canadian Curtiss-Wright, Ltd. (430)
Canadian General Electric, Ltd. Fuel elements, reactors. (426)
Canadian Patents and Development Corp. (430)
Canadian Vickers, Ltd. (430)
Canadian Westinghouse Co., Ltd. Reactors. (420)
Catalytic Construction of Canada, Ltd. (420)

← Tear out this AtomFair directory and take it to Cleveland



AtomFair Directory . . . continued

Central Research Laboratories, Inc. Manipulators and other remote handling equipment. (304)
Charleston Rubber Co. Glove boxes and radiation-shielded gloves. (711)
Clevite Corp. (516)
Cleveland Hard Facing, Inc. (816)
Combustion Engineering, Inc. Fuel elements, heat exchangers, pressure vessels, reactors. (204)
Commissariat a l'Energie Atomique. (822, 823, 825)
Computing Devices of Canada, Ltd. (430)
Conference Book Service. (916)
Consultants Bureau, Inc. Books, journals, translations. (720)
Cooper Metallurgical Associates. Boron, borides, ferrochrome and chromium. (518)
Cooper-Trent Blueprint & Microfilm Corp. (505)
Corning Glass Works. (233)
Crane Co. Valves. (608, 610, 612)
Crawford Fitting Co. (333)
Curtiss-Wright Corp. Fuel elements, reactors. (429)

Davison Chemical Co. Div., W. R. Grace & Co. Thorium and uranium metal, alloys and compounds. (208)

The Edlow Lead Co. Lead and lead alloys, shielded containers, waste-disposal systems. (118)
Eldorado Electronics Co. Analyzers and counters. (811)
Eldorado Mining & Refining, Ltd. (420)
Electronic Associates, Ltd. Nuclear instrumentation. (426)
Encyclopaedia Britannica. (513)
Englehard Industries, Inc. Fuel elements. (500)
Erskine-Healy, Inc. Dry-box gloves. (702)

Federated Metals Canada, Ltd. Shielding (430)
The Fenn Mfg Co. Fuel-element-fabricating equipment. (220)
Ferranti-Packard Electric, Ltd. (426)
Flanders Filters, Inc. (520)
Florida Development Commission. (819)
Foster Engineering Co. Flowmeters, valves. (101)
The Foxboro Co. Process instrumentation. (329)
Charles E. Frosst & Co. Isotopes. (420, 426)

General Atomic Div., General Dynamics Corp. Fuel elements, reactors, thermonuclear equipment. (115)
General Electric Co. (133)
General Mills, Inc. Manipulators. (229)
The Griscom-Russell Co. Heat exchangers, pressure vessels, waste-concentration systems. (419)

Hagan Chemicals & Controls, Inc. Decontaminants, ion-exchange equipment. (710)
Hamner Electronics Co., Inc. Analyzers, counting-rate meters, radioactivity monitors, scalers, spectrometers. (724)
The Harshaw Chemical Co. Scintillators. (624)
Harvey Aluminum, Inc. Aluminum and zirconium. (507)
High Voltage Engineering Corp. Neutron sources, particle accelerators, radiographic equipment. (412)
Hughes Aircraft Co. (124)

Instron Engineering Corp. Testing equipment. (108)
International Nickel Co., Inc. (615, 617, 619)

Keithley Instruments, Inc. Electrometers, period meters, radioactivity monitors. (301)
O. G. Kelley & Co. (321)
Knapp Mills, Inc. Shielded containers, shielding. (425)
Kollmorgen Optical Corp. Viewing equipment. (501)

Ladish Co. Drop forgings and pipe fittings. (221)
Lerma Engineering Corp. Viewing equipment. (709)
Lindsay Chemical Div., American Potash & Chemical Corp. Thorium and rare-earth oxides. (219)
Lundell & Co. (720)

M & C Nuclear, Inc. Fuel elements. (112)
MSA Research Corp. Electromagnetic pumps, magnetic flowmeters. (618, 620)
Mallinckrodt Chemical Works. Uranium metal, alloys and compounds. (128)
Mallory-Sharon Metals Corp. Hafnium and zirconium. (325)
The Martin Co. Control rods and drive systems, fuel elements and handling equipment, isotopes, reactors. (305)
Massachusetts Department of Commerce. (202)
Measurement Engineering, Ltd. (420)
George T. Meilon, Inc. Dosimeters. (817)
Merk & Co., Ltd. Isotopes. (426)
Minneapolis-Honeywell Regulator Co. (224)

National Beryllia Corp. Ceramics. (511)
National Lead Co. Shielded containers, shielding. (132)
Nuclear-Chicago Corp. Nuclear instrumentation. (421)
Nuclear Development Corp. of America. Control-rod drive systems, fuel elements, reactors. (225)
Nuclear Electronics Corp. Analyzers, counters, counting-rate meters, radioactivity monitors, scalers, spectrometers. (701)
Nuclear Enterprises, Ltd. Scintillators. (430)
Nuclear Measurements Corp. Chromatographic apparatus, counters, radioactivity standards and monitors, scalers, spectrometers. (616)
NUCLEONICS, McGraw-Hill Publishing Co., Inc. (607)

The Ohio Bell Telephone Co. (601)
Ontario Research Foundation (430)
Oregon Metallurgical Corp. Zirconium and titanium castings and vanadium metal. (703)
Orenda Engines, Ltd. (420)

Pacific Engineering Co. Pressure vessels, shielded containers, shielding, waste-disposal systems. (105)
Penberthy Instrument Co. High-density glass, shielding windows. (408)
Pittsburgh Plate Glass Co. Shielding windows. (524)
Pye, Ltd. Viewing equipment. (716)

Racey MacCallum & Associates, Ltd. (420)
Radiation Counter Laboratories, Inc. Nuclear instrumentation. (228)
Radiation Instrument Development Laboratory, Inc. Analyzers, counters, counting-rate meters, radioactivity monitors, sample holders and changers, scalers, spectrometers. (707)
Reuter-Stokes Electronic Components, Inc. Nuclear instrumentation. (818)
Research Equipment Co. Shielding windows. (402)

Saint-Gobain. (822, 823, 825)
Sarnia Inspection Co. (426)
Shell Oil Co. Lubricants. (309)
Sperry Gyroscope Co. of Canada, Ltd. (426)
Swartwout Co. Process instrumentation. (512)
Sylvania-Corning Nuclear Corp. Fuel elements. (232)

Technical Associates. Counters, counting-rate meters, dosimeters, radioactivity monitors, scalers, shielding. (218)
Technical Measurement Corp. Analyzers, counters, counting-rate meters, scalers, spectrometers. (319)
Thompson Ramo Woolridge, Inc. (312, 413)
Tracerlab, Inc. Nuclear instrumentation. (439)
Turco Products, Inc. Decontaminants. (806)

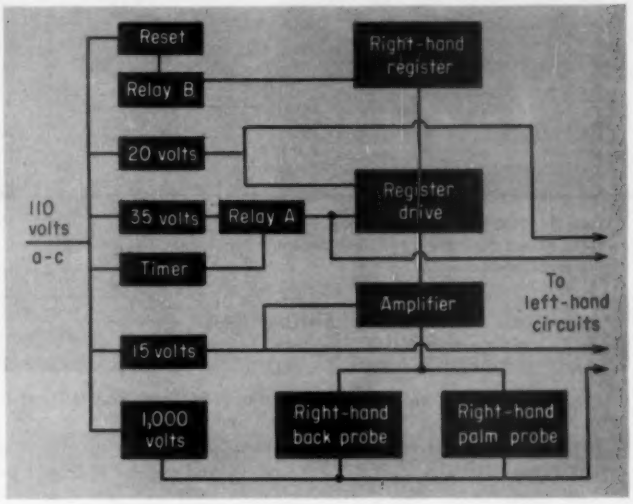
Union Carbide Corp. (209, 213)
United Nations Sales Promotion Unit. (400)
United Shoe Machinery Corp. Control-rod drive systems, fuel-element handling equipment. (129)
United States Atomic Energy Commission. (910, 912, 1011, 1013)
United States Department of Commerce. (521)
United States Radium Corp. Isotopes, radioactivity standards, sources. (718)
United States Steel Corp. (138, 141)

D. Van Nostrand Corp. Books. (807)
Vard, Inc. Nuclear instrumentation. (404)
Velan Engineering, Ltd. Valves. (420)
Vickers, Ltd. (104)
The Victoreen Instrument Co. Analyzers, counters, counting-rate meters, dosimeters, electrometers, radioactivity standards and monitors, scalers, spectrometers. (508, 510)
Vitro Corp. of America. (433)

Westinghouse Electric Corp. (318, 320, 324)
Winnett Boyd, Ltd. Reactors. (420)
Wolverine Tube Div., Calumet & Hecla, Inc. (111)

FIG. 1. NEW AND OLD MONITORS. Scintillation hand counter for alpha contamination at left replaces ionization-type Four-Fold

FIG. 2. BLOCK DIAGRAM shows how back and palm probes operate in parallel to drive right-hand register. Identical circuits count left hand



Increased Reliability; Decreased Size—

Transistors Shrink Contamination Detectors

Transistor design produces a compact, reliable alpha hand monitor to replace a temperamental, expensive predecessor. A companion is a tiny instrument with both detector and adjustable pulse-height analyzer

By W. G. SPEAR
Hanford Atomic Products Operation, General Electric Company, Richland, Washington

TRANSISTORS HAVE MADE POSSIBLE two compact and convenient laboratory instruments: a compact monitor for alpha contamination on the hands and a portable spectrum analyzer that is useful in identifying radioactive contamination. The hand monitor replaces a bulky vacuum-tube device, Four-Fold, which was difficult to adjust and expensive to maintain.

The portable spectrum analyzer has an adjustable single-window analyzer and a scintillation detector. Its resolution is adequate for our purposes although not as good as that of large a-c-powered instruments. Its amplifier is nearly linear, and a calibration curve, made with calibrating nuclides, can be used to correct whatever nonlinearity exists.

ALPHA HAND COUNTER

Figure 1 shows our transistor alpha hand counter and the standard Four-Fold monitor that it replaces. The new model uses scintillation fluors on light pipes; its predecessor uses ionization chambers. The low inherent background and high sensitivity of the scintillation device give it great advantages over the Four-Fold.

The older instruments perform satisfactorily for only short times after exacting adjustments of circuits and chamber potentials. Slight increase in high potential causes probe breakdown. Slight decrease causes abrupt reduction of sensitivity. Maintenance costs amount to half the original investment

FIG. 3. FRONT PANEL of alpha monitor. Round dials are adjustable "warning level" indicators

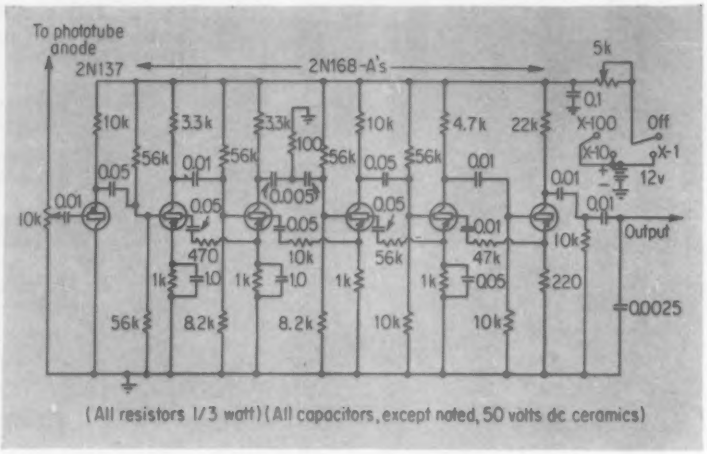


FIG. 4. SIX-STAGE AMPLIFIER has voltage gain of 1,000 for 1-mv, 1-μsec negative pulse input

each year. Sensitivity limit is 500–1,000 dpm.

In contrast our scintillation counter reliably indicates uniformly distributed plutonium contamination at levels less than 200 dpm. The experimental instrument has operated continuously for 14 months with no maintenance or recalibration costs. It is less than ⅓ as large as the older instrument. Its cost is $2,200, of which $900 is for the four phototubes. So far our maintenance costs are zero.

How It Works

Figure 2 is a block diagram of the instrument and Fig. 3 shows its front panel. There are four probes, one for the back of each hand and one for each palm. Each consists of a fluor, a light pipe and a photomultiplier tube. The two right-hand probes feed in parallel through an amplifier and a register drive to the right-hand register. A parallel set of probes, amplifier, drive and register operate from the same controls and power supplies to count the left hand.

Scintillator System

Each of the four probes has an RCA 6372 side-window phototube with a 12-in² photocathode. Each phototube is used with a Lucite light pipe that has an 8 × 4.5-in. sensitive area. This area can be increased to 6 × 10 in. with good results. The light pipe tapers from the sensitive face to match the 2.5-in. diameter of the cathode. Dow-Corning silicone fluid optically couples pipe and tube. The pipe has a grooved semicircular back that matches the tube directly.

Except for the grooved area, back and sides of the pipe are covered with aluminum foil for light reflection purposes.

Fluors. The 8 × 4.5-in. face of the pipe is sprayed with a zinc-sulfide mixture to make a uniform coating with a dry thickness of ~10 mg/cm². The solution is made of eight parts toluene to one of Amphenol Type 912 polystyrene coil dope. Into this goes ~0.1 gm of scintillation-grade silver-activated zinc sulfide for each cubic centimeter of the original solution. The mixture is thoroughly shaken and sprayed onto the Lucite surface with an artist's air brush.

The dried fluor is covered with one layer of 0.2-mg/cm² dutch-leaf aluminum. This in turn is covered with one layer of 0.9-mg/cm² double-aluminum-coated Mylar. The probe goes into an aluminum holder with a square-pierced brass face protector that has 70% open area.

Efficiency. At the center the probe has a geometrical efficiency of 25–30% for plutonium alpha particles. Edge efficiencies are 20–25%, which indicates that there is almost uniform efficiency over the face. On the average, alpha-caused pulses from edges and corners are about ⅓ as high as the center pulses. Even the smaller pulses are at least five times as high as phototube noise pulses. Thus signal-to-noise discrimination is easy. The completed probe can be used face up in normal room light with no increase in background from light leakage.

The 15-sec background for each probe is about two pulses or one full count on the register. Meanwhile a 50-dpm plutonium alpha point source at the probe center produces about two register counts. Thus 50 dpm is about the ultimate sensitivity. This sensitivity is about 10 times that of a well-adjusted Four-Fold.

How We Calibrate the Spectrum Analyzer

Since our amplifier is not strictly linear, we must establish a calibration for the portable gamma analyzer. Window circuitry is adjusted first with a calibrated pulse generator. Then the controls are locked so that each of the window-width circuits has a constant threshold.

For calibration we use radionuclides. First we use Cs^{137} and set the input potentiometer so that the base-line-dial setting is "true" for the 661-kev photopeak. Then we lock this setting and do not adjust it again. If the control is inadvertently maladjusted in the field, the user can obtain a Cs^{137} source and readjust. Other nuclides such as Ba^{133} and Co^{60} are used to establish the rest of the calibration.

For some purposes it would be better to have the base-line setting at the front end of the amplifier. However, our input pulses are generally 1–10 mv in amplitude, and the 10-turn potentiometer caused excessive ringing at the input. As it is used now, it is at a low-impedance point and causes no trouble of this kind.

Circuits

Transistor circuits for our system consist of power supplies, six-stage cascade amplifiers and driving circuits for the registers. Both amplifier and driving circuits have been made on plug-in printed-circuit boards. Commercial transistor power supplies are used for the lower potentials, and we designed one supply for 1,000 volts.

Each pair of probes drives a six-stage transistor amplifier shown in Fig. 4. It is a cascaded amplifier with stage-by-stage feedback. With a 1-mv, 1-μsec negative pulse input, voltage gain is 1,000. The variable input resistor permits pulse discrimination. Because of the large signal-to-noise ratio, adjustment is not critical. Alpha-caused input pulses range from −10 to −50 mv and have rise times of 0.5–2.0 μsec. They are reduced with the input rheostat to produce 1–5-volt negative output pulses. An input rise time of 0.2 μsec produces an output rise time of 0.8 μsec in an unshunted 10,000-ohm load. This is shunted by a 0.0025-μf capacitor to make 10-μsec-wide pulses suitable for the register-drive circuit.

Register drive. Figure 5 shows the circuit for driving each of the registers. It has two GE 2N168-A transistors in a one-shot multivibrator circuit. The first transistor, TR-1, is normally conducting so that the relay coil is normally activated, and the register coil is energized. The second transistor is normally cut off, and B+ appears on its collector.

An incoming negative pulse of proper size and width cuts off TR-1 and turns on TR-2. Recovery time is controlled by 4-μf capacitor C-1 and the 100,000-ohm resistor in series with it. The resulting 40-msec time constant is more than adequate to release the relay. After 40 msec the circuit is ready for its next pulse. The instrument is not designed for high counting rates; a plutonium source of 2,500 dpm will jam it. Jamming is indicated by bright glowing of the neon bulb.

As it is presently connected, the circuit produces half a register count for each input pulse.

High-potential supply. Figure 6 is the circuit we designed to supply 500 μa at 1,000 volts for our four phototubes. Our phototubes vary extensively in gain. Thus it is good to have a high potential with an individual dropping rheostat for each tube.

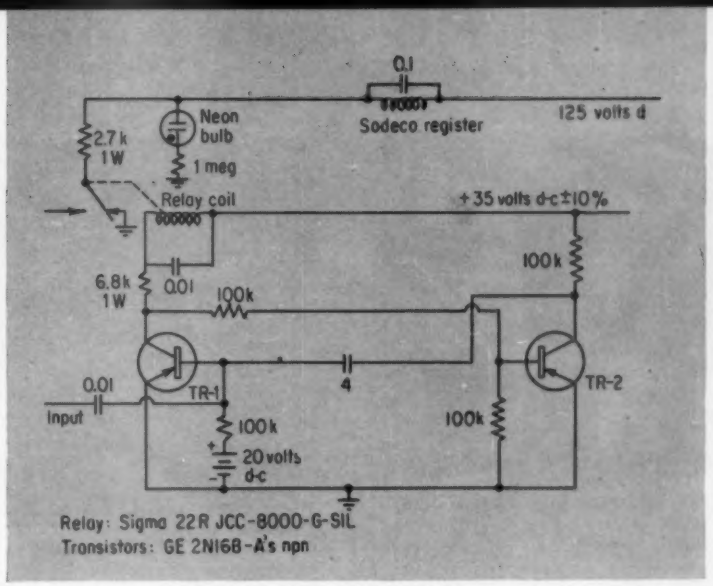


FIG. 5. ONE-SHOT MULTIVIBRATOR supplies power to actuate Sodeco register

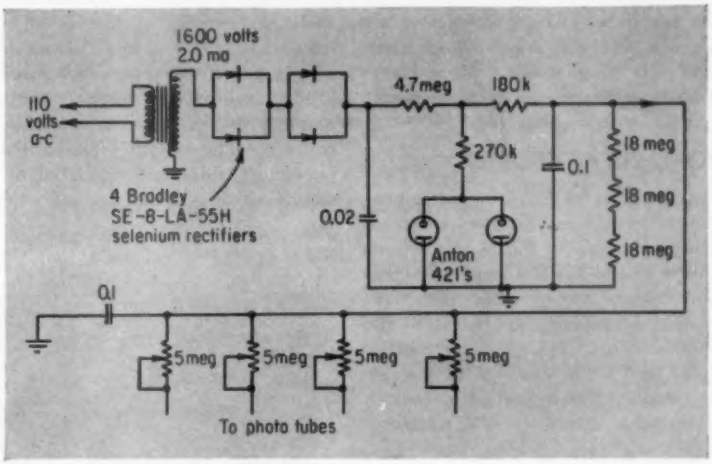


FIG. 6. SPECIAL POWER SUPPLY feeds 900–1,000 volts through adjustable dropping resistors to each of four phototubes

Our supply is a half-wave selenium-diode rectifier with capacitor input and conventional filtering. It has two 1,000-volt corona regulators in parallel. Regulation is not critical because of the favorable signal-to-noise ratio.

Controls

Figure 7 is the switch-and-relay diagram. When the monitor is ready to count, the ready light glows and neither relay is energized. Lifting the inserted right hand slightly closes hand-probe switch S-2 to start the timer. This energizes the count relay and count light. The 35-volt potential is applied to the register drive circuits, and 125 volts d-c is applied to the Sodeco drive coils. The timer's holding contacts keep it operating when the momentary-contact hand-probe switch is released. After the interval set on

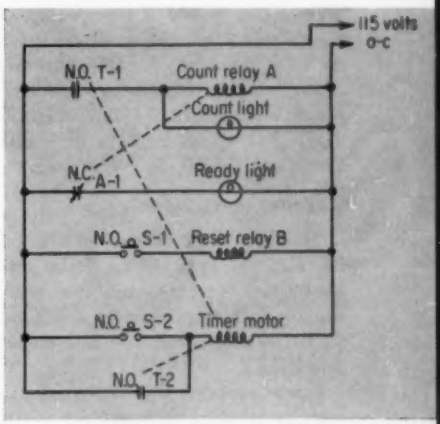


FIG. 7. CONTROL CIRCUITS include start button, timer and reset button. A-2 contacts, normally open, control 35 volts d-c to register drive. B-1 contacts, normally open, control 125 volts d-c to registers

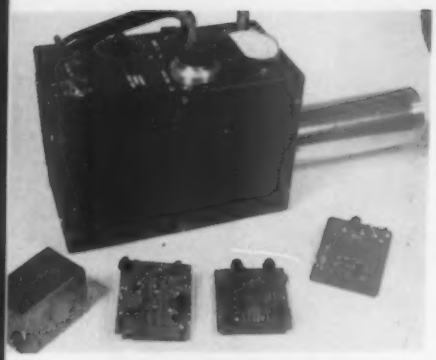


FIG. 8. PORTABLE GAMMA-SPECTRUM ANALYZER includes 2 × 2-in. NaI(Tl) crystal and movable single window

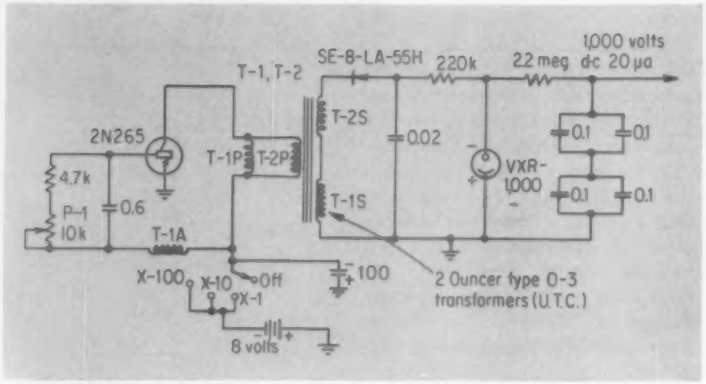


FIG. 9. HIGH-POTENTIAL SUPPLY uses single-transistor blocking oscillator and miniature selenium rectifier

the timer—usually 15 sec—the timer releases, and count relay and count light are deenergized. Momentary-contact switch S-1 resets the registers and the cycle is completed.

PORTABLE KICKSORTER

Another useful transistor instrument is our portable gamma spectrum analyzer shown in Fig. 8. It weighs only 7 lb and has a continuous-operation battery life of ~250 hr. With present adjustment, ten turns of the photon-energy dial spans an energy range of 0.1–1.5 Mev. With a single adjustment the upper limit can be increased to 2.0 Mev. The minimum stable window width is 10–20 kev, which gives a system resolution with Cs^{137} of 13.4%. The usual operating window width is ~40 kev.

Operating power is 0.36 watt. As Fig. 8 shows, plug-in printed circuits are used for simple maintenance and repair. We have made two prototype instruments using the same circuits. They are ~⅔ as large as the one of Fig. 8 and weigh only ~6 lb each.

Circuits

The instrument consists of a 2 × 2-in. NaI(Tl) crystal, an RCA 6655 phototube, a 1,000-volt d-c power supply, a linear amplifier, a window-width discriminator, and a counting-rate circuit.

Power supply. Figure 9 shows the high-potential supply, a slight modification of an earlier model (*1*). The single transistor operates as a blocking oscillator. Its repetition rate can be varied from 350 to 700 pps by changing the setting of the 10,000-ohm, 10-turn rheostat in the base circuit and, if necessary, the 0.6-μf capacitor. Blocking-oscillator pulses are increased in magnitude by the transformers and rectified by a miniature selenium rectifier. The output, filtered by a double *RC* filter and regulated by a corona tube, is 20–25 μa at −1,000 volts. Nominal conversion efficiency is 30%, and this can be increased to 35–40% by proper adjustment of the 10,000-ohm rheostat. The supply is contained in a thin steel can that measures 1½ × 2 × 2¾ in.

Amplifier. With the exception of an additional gain control between tran-

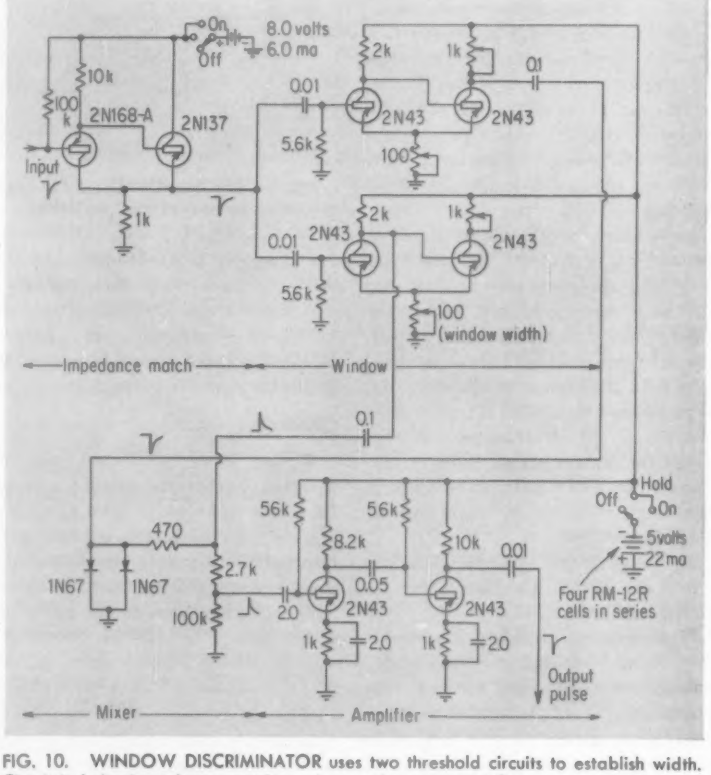


FIG. 10. WINDOW DISCRIMINATOR uses two threshold circuits to establish width. Circuit includes impedance matcher, mixer and output amplifier

sistors 3 and 4, the amplifier is essentially the same as that of Fig. 4. It is nearly linear for negative input pulses of 1–15 mv with a maximum voltage gain of 750. The 10-turn, 100-ohm gain control following transistor 3 is the base-line control. Shunting the load with the capacitor shown leads to 2.0-μsec-rise-time and 10-μsec-wide output pulses from input pulses of 0.2-μsec rise time and 1-μsec width.

Alpha cutoff for the transistors—the frequency at which grounded-base gain drops to 3 db below the low-frequency value—is 7.0 megacycles. This gives the amplifier a bandwidth of ~1 megacycle. The noise level, referred to the input, is ~50 μv, far below the normal 1–10-mv signal level.

Window discriminator. In Fig. 10 is shown the circuit of the window-width discriminator. It includes an impedance-matching circuit, the window, a passive mixer and an amplifier used to drive the counting-rate-meter circuit.

The first two transistors are an *npn*-to-*pnp* matching circuit. It is essentially a two-stage amplifier with a gain of ~1 and very-low-impedance output (*2*). There is no inversion; negative input pulses produce negative output pulses.

Four GE *pnp* transistors form the window. Each of the two pairs forms a threshold circuit that responds only to pulses greater than a value set by the common emitter resistor. The upper pair are set to respond to pulses greater than 1.0 volt. Thus the emitter resistor of the lower pair becomes the window-width control.

In operation each pair of transistors produces an output pulse of about 3.0 volts for any input pulse that exceeds the threshold. Output from the upper pair is negative, and that from the lower pair is positive. The two are combined in the mixer so that the input to the amplifier section is either a positive pulse or zero.

For stable operation the window width is 0.05–0.1 volt. This is equivalent to a 10–20-kev photon-energy range. Resolution is difficult for gamma energies closer than 40–50 kev. Inherent resolution depends largely on the regulation of the high-potential supply.

Two *pnp* transistors in cascade form the amplifier that changes an 0.5-volt pulse from the mixer to an appropriate 2–3-volt pulse to drive the counting-rate circuit that is shown in Fig. 11.

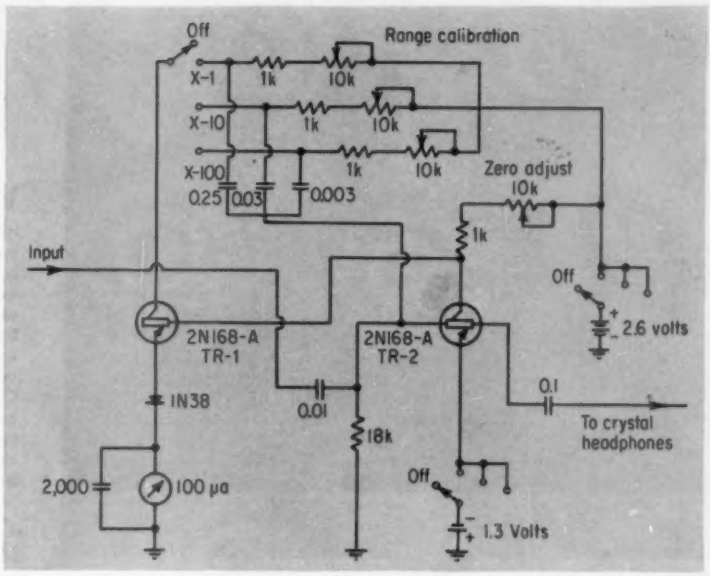


FIG. 11. COUNTING-RATE-METER CIRCUIT has triggered one-shot multivibrator that responds to negative input pulses greater than 0.1 volt

Counting-rate circuit. The one-shot multivibrator circuit of Fig. 11 operates the counting-rate meter (*3*). Biases hold TR-1 normally off and TR-2 normally on. An incoming negative pulse greater than 0.1 volt cuts off TR-2 to start the multivibrator action. The time constant of one of the three range-calibration capacitors in combination with the base resistor of TR-2 determines the pulse length. Three potentiometers allow setting maximum counting rates on the three ranges at 1,000, 10,000 and 100,000 cps. The collector rheostat of TR-2 sets the conduction point and consequently the sensitivity level.

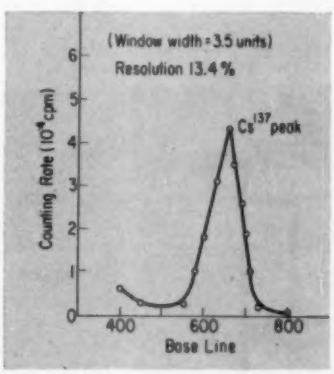


FIG. 12. Cs^{137} RESOLUTION is 13.4%

Results

Figure 12 shows the 661-kev photopeak of Cs^{137} as observed with this instrument. Resolution is 13.4%, which is entirely adequate for our purposes. More precise and more costly a-c-operated equipment could be expected to provide resolution of 7–9%.

Several other similar instruments have come out of this program. Similar to the alpha-contamination monitor is a counter designed for simultaneous recognition of alpha, beta and gamma activities on filters (*4*). It has one light-pipe probe for alphas and another, almost identical, for betas and gammas. Center efficiencies are 20–25% for alphas, 20–25% for 500-kev betas and 0.8–1% for 600-kev photons.

Another instrument simultaneously monitors alpha, beta and gamma contamination on hands and shoes (*5*).

* * *

This article is based on the author's two reports HW-52787 Rev. and HW-54287 Rev. The author acknowledges suggestions of M. O. Rankin, E. W. Groff, G. E. Driver and L. V. Zuerner.

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1 MOMENTOUS DAY—Tuesday, January 20, 1959—begins with final briefing of startup crew for Industrial Reactor Laboratories, Inc.'s new research reactor. IRL is a $4.5-million nuclear research center established by 10 noncompeting industrial companies (NU, Oct. '56, R-5) near Plainsboro, N. J. Facility's AMF-designed reactor is largest (5-Mw) privately owned swimming-pool reactor in U. S. Bob Cochran (left)' and Dave Anderson (right) and other members of AMF crew had helped start up other reactors before; exclusive NUCLEONICS photos show how they brought this one to criticality

IRL Reactor Goes

2 STORAGE VAULT is first stop for Cochran to break out reactor's plastic-covered fuel charge

4 HEALTH PHYSICIST Andy Hull monitors cask containing Ra-Be source as it comes from shipping crate. Source is needed to supply detectable neutron level during approach to critical

5 FUEL ELEMENT #1 goes into the water as Anderson begins loading elements into pool storage racks prior to charging core

3 WATER SAMPLE is checked before fuel loading begins. Filling of pool, started during the night, is approaching completion

6 CONTROL BOARD keeps score as fuel transfer from storage vault to reactor pool continues. Boyd Maxon records latest change

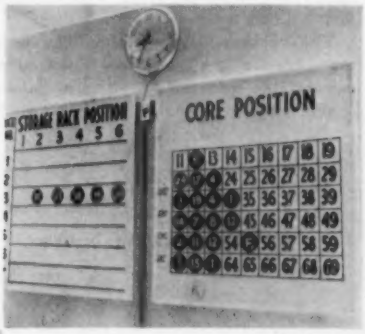
7 LOADING BEGINS as first fuel element is placed in lattice position with fuel handling tool and crane. Crew had worked through lunch, ate sandwiches and coffee in adjacent building during odd moments

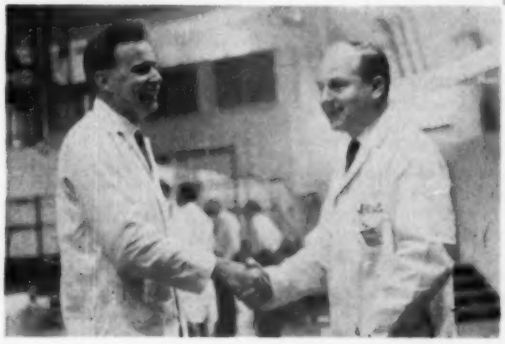
8 HALF-LOADED core under 30 ft of water takes on eerie view for workers on bridge. After loading each element, crew withdraws control rods and measures neutron-flux level

Critical

9 ALMOST THERE—tension builds up in control room as decisive fuel element is lowered into place. Plot of inverse of neutron-flux level had been extrapolated to give critical number of elements

10 CRITICAL CONFIGURATION shows on control board. Whole startup operation had taken place without single hitch





11 WE MADE IT!—critical congratulations are shared by Anderson and Schulze (right), AMF Atomics Engineering Dept. Manager. Afterwards, group inserted control rods and went off to champagne-dinner celebration

Computing Aid for Reactor-Kinetics Equations

By HENRI SMETS
*Brookhaven National Laboratory, Upton, N. Y.**

THE GRAPHICAL AID presented here is a convenient tool for the computation of many reactor-kinetics problems. Its chief advantage lies in its versatility—it can be used for all values of neutron lifetime and for a wide range of reactivities. It can be used to compute the roots of the inhour equation or the exact response to a ramp, exponential or inverse-function variation of reactivity (*1*). It can also aid the computation of the kernel of the integral equation of reactor kinetics.

How It Works

In many problems of reactor kinetics at low power, one must determine the roots s_j of the equation

$$as + b\frac{\beta}{l} + c\sum_i \frac{\beta_i\lambda_i}{l(s+\lambda_i)} = \frac{d}{l} \qquad (1)$$

where l is the effective neutron lifetime, β_i and λ_i are the yield and decay constants of delayed-neutron emitters of the group i, $\beta = \Sigma\beta_i$ and a, b, c and d are constants. Further, if

$$Y(s) = \frac{d}{\beta c} - \frac{b}{c} - \frac{asl}{c\beta} \qquad (2)$$

$$Z(s) = \sum_i \frac{\beta_i\lambda_i}{\beta(s+\lambda_i)} \qquad (3)$$

the roots s_j are the abscissae of the intersection of the straight line defined by Eq. 2 and the curve defined by Eq. 3. Therefore, if an accurate plot of the function $Z(s)$ is available, the determination of the roots of Eq. 1 reduces to a simple geometrical construction.

The function $Z(s)$ for thermal fissions in U^{235} was computed for $-4.5 < s < 1.4\ \text{sec}^{-1}$ and is plotted in Figs. 1 and 2. The calculations were made with the latest available data (*2*).

When s is very small ($|s| \ll 0.003\ \text{sec}^{-1}$)

$$Z(s) \simeq 1 - \sum_i \frac{\beta_i}{\beta\lambda_i}s = 1 - \frac{s}{0.07684} \qquad (4)$$

and when s is very large ($|s| \gg 10\ \text{sec}^{-1}$)

$$Z(s) \simeq \sum_i \frac{\beta_i\lambda_i}{\beta} \times \frac{1}{s} = \frac{0.4053}{s} \qquad (5)$$

Examples

With Figs. 1 and 2, the roots s_j can be determined with an accuracy better than 1%, as will be shown. A higher accuracy is not necessary because the parameters β_i and λ_i are known only with an accuracy of 5% (*2*).

Response of a reactor to a step increase of reactivity. The response of a reactor to a step increase of reactivity (*3*) is

$$n(t) = L^{-1}\left[\frac{n_o + \sum_i \frac{P_i\lambda_i C_{io}}{s+\lambda_i} + S_{(s)}}{s - \frac{k(1-\gamma\beta)-\gamma\beta}{l} - \frac{(1+k)\gamma}{l}\sum_i \frac{\beta_i\lambda_i}{s+\lambda_i}}\right] = \sum A_j e^{s_j t} \qquad (6)$$

where n_o and C_{io} are the initial values of the neutron density n and the delayed-neutron-emitter concentration C_i for the group i, k the reactivity, P and P_i the slowing-down density per unit source strength respectively for prompt and delayed neutrons of the group i, and γ the average efficiency of the delayed neutrons ($\gamma = \Sigma_i \beta_i P_i / \Sigma_i \beta_i P$).

The exponents s_j are the zeros of the denominator of Eq. 6. They are found by solving Eq. 1 with $a = 1, b = -c = \gamma(1+k)$ and $d = k$. This is then equivalent to the inhour equation. If $k/\beta = 0.1$, $\beta/l = 10\ \text{sec}^{-1}$ and $\gamma = 1$, Eq. 2 becomes

$$Y(s) = -0.1 + 1 + s/10 \qquad (7)$$

Drawing the line given by Eq. 7 across Figs. 1 and 2 (at the proper scale), it is found that the roots of the denominator of Eq. 6 are (in sec^{-1}) $s_1 = +0.0105$, $s_2 = -0.01382$, $s_3 = -0.0626$, $s_4 = -0.1862$, $s_5 = -0.997$, $s_6 = -2.845$. The last root is outside Fig. 2 but can be found by solving $Y(s) = Z(s)$ where $Z(s) = 0.4053/s$. The solution is $s_7 = -8.53\ \text{sec}^{-1}$.

When the seven roots are known, the coefficients A_j are found by calculation of the residues. This solution is $n(t)/n_o = 1.432e^{0.0105t} - 0.03e^{-0.01382t} - 0.0615e^{-0.0626t} - 0.042e^{-0.1862t} - 0.0205e^{-0.997t} - 0.018e^{-2.845t} - 0.258e^{-8.53t}$.

Characteristic frequencies of the reactor transfer function. The reactor transfer function (*4*) is given by

$$\frac{\delta n_{(s)}}{n_o \delta k_{(s)}} = \frac{1 - \beta + \sum_i \frac{\beta_i\lambda_i}{s+\lambda_i}}{ls - [k_o(1-\gamma\beta) - \gamma\beta] - (1+k_o)\gamma\sum_i \frac{\beta_i\lambda_i}{s+\lambda_i}} = \frac{(1-\beta)\prod(s+s_j^*)}{l\prod(s+s_j)} \qquad (8)$$

where k_o is the average reactivity such that the average neutron density remains constant during the oscillator test [when $S = 0$, k_o is slightly negative because of nonlinear effects (*5*)]. The denominator of Eq. 8 is identical with the denominator of Eq. 6 if $k = k_o$. Therefore, the poles s_j are found as explained in the previous example. In Fig. 1, the effect of a variation of the neutron lifetime on the values of s_j is displayed in the inset. It is seen that only the two largest roots, s_6 and s_7, change appreciably with l. The zeros s_j^* of the transfer function are very close to λ_i and are, for $\gamma = 1$, $s_1^* = -0.012438$, $s_2^* = -0.030467$, $s_3^* = -0.11126$, $s_4^* = -0.30064$, $s_5^* = -1.13517$, $s_6^* = -3.0132$.

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* PRESENT ADDRESS: 24 Ave. d'Orbaix, Brussels, Belgium. This work was performed under the auspices of the U. S. AEC and the Belgian-American Educational Foundation. It is part of a D.Sc. thesis written under Prof. Elias P. Gyftopoulos of MIT.

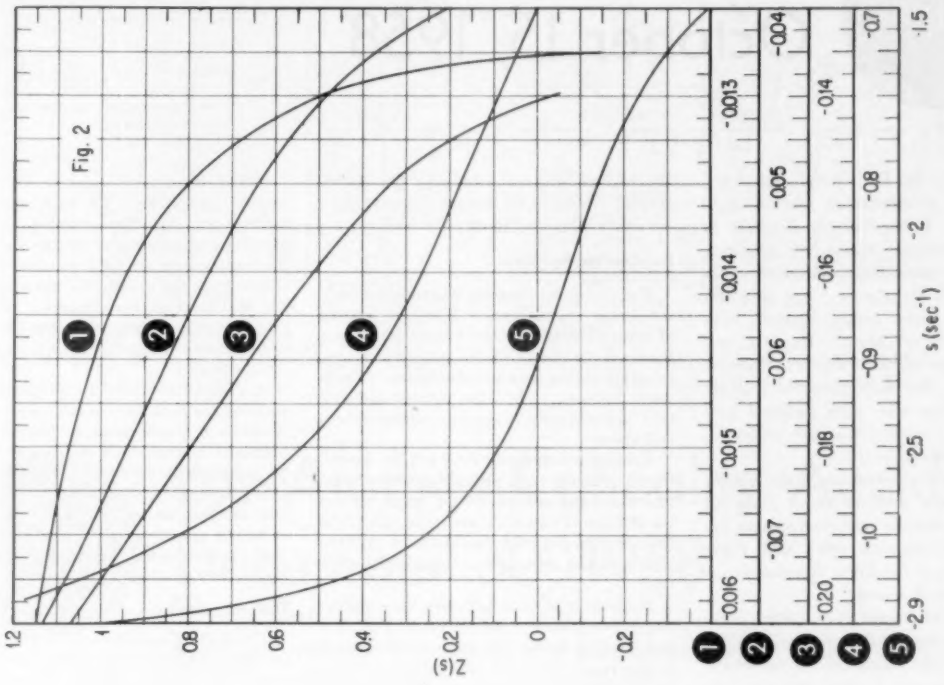


FIG. 2. Function Z(s) is here plotted over a range of negative values of s

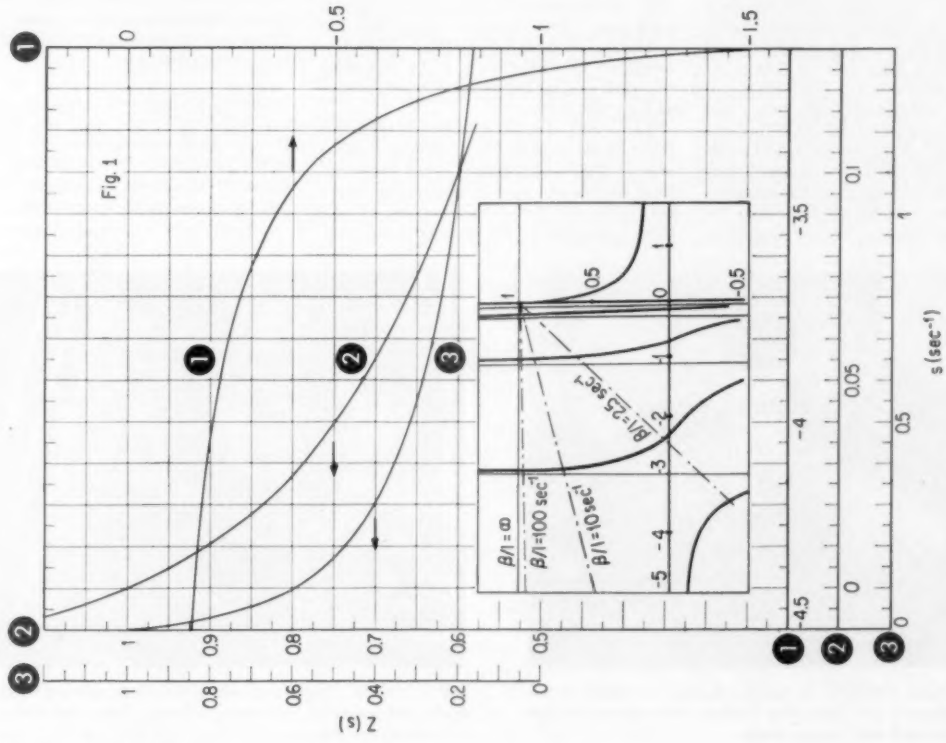


FIG. 1. Function Z(s) vs. s (see Eq. 2). Inset shows greater range of function

Yugoslavian Criticality Accident, October 15, 1958

EDITORS' NOTE: *In an accidental supercriticality of a zero-power reactor, eight people at the Boris Kidrich Institute of Nuclear Sciences, Vinca, Yugoslavia, received above-permissible radiation exposures. Six of them were flown to Paris for treatment under Henri Jammet, head of the Service of Atomic Hygiene and Radiopathology of the Curie Foundation. One died (1); five have recovered and returned to Yugoslavia. An unusual portion of their treatment was the successful use of bone-marrow grafts (2).*

The following description of the critical facility and the accident result from an exchange of airmail and radiograms between the NUCLEONICS *office and Pavle Savic, director of the Boris Kidrich Institute of Nuclear Sciences.*

In answering several NUCLEONICS *questions Savic indicated that the accident did no damage to the reactor or its materials. Redesign to prevent a recurrence includes installation of a safety interlock system and a shield for personnel.*

THE CRITICAL FACILITY in which the accident occurred is a natural-uranium–heavy-water assembly (*3, 4*). Top and side views of it are shown in Figs. 1 and 2. It is unshielded and unreflected. The fuel is aluminum clad natural-uranium rods, and control is accomplished by adjusting the moderator level. Two cadmium safety rods are available, but before the accident they were not interlocked with the flux recorder. If the recorder was on, it controlled the safety rods, but nothing prevented starting the reactor without switching on the recorder. Some of the reactor characteristics are listed in the table on page 155.

Design of Facility

The zero-power reactor was built for reactor-design experiments. The first loading of natural uranium and heavy water was designed to gain reactor experience and accurate values for natural-uranium–heavy-water lattices. The bare, unreflected system makes it easy to compare measurement and theory.

Reflection is reduced to $<4\%$ by mounting the reactor tank at least 4 meters from any reflecting surface. Fuel slugs rest on the bottom of the tank, and their spacing is fixed by two grids—one on the bottom of the tank and the other about 27 cm below the lid.

Moderator level is adjusted by a pump-and-valve system. As shown in Fig. 3, a storage tank below the reactor is connected to the reactor tank by two pipes. A 2-in. gravity line provides an outlet, and a canned rotor pump and a 1-in. line provide inlet. The pump operates at two speeds to change moderator level at rates of 2.5 and 0.8 cm/min. Near criticality reactivity changes at 1.5%/cm. Two lowering speeds are also available: 11 and 1.7 cm/min. Level is measured to within 0.2 mm by observing electrical contact between the water surface and a point probe.

Three BF_3 counters of different sensitivities indicate neutron flux. They are placed around the tank on the lower platform. Each has its own preamplifier, linear amplifier, scaler and five-decade ratemeter. All three ratemeters are connected to a recorder.

Safety equipment consists of a supervisor's control key, the two safety rods, neutron-flux monitors coupled to audible alarms, and automatic shutdown circuits. The safety rods are held by electromagnets that require the presence of the supervisor's key and have separate drives. On release they fall by gravity until checked by spring-type shock absorbers in the driving mechanism.

Approach to criticality is monitored by plotting the reciprocal of the multiplication. A 500 mc Ra-Be neutron source can be placed at any point on the axis of the tank by inserting it through a source-injection tube at the center of the lid. Observing the flux decrease as the source is removed reveals the reactor period. Sudden removal of the cadmium rods has been used to measure periods as short as 10 sec.

The Accident

The lack of an interlock system and the fact that monitors and safety circuits were turned off made possible the accident of October 15. An uncontrolled rise of heavy water resulted in a supercriticality that was discovered only when operating personnel smelled ozone. Figure 4 shows where people were standing near the tank at the time. The following official report of the accident is quoted verbatim:

During a subcritical experiment on October 15th, 1958, the zero energy reactor (heavy water-natural uranium assembly) at the Institute of Nuclear Sciences "Boris Kidrich" became uncontrolledly supercritical. Six men in the immediate vicinity of

Continued on page 154

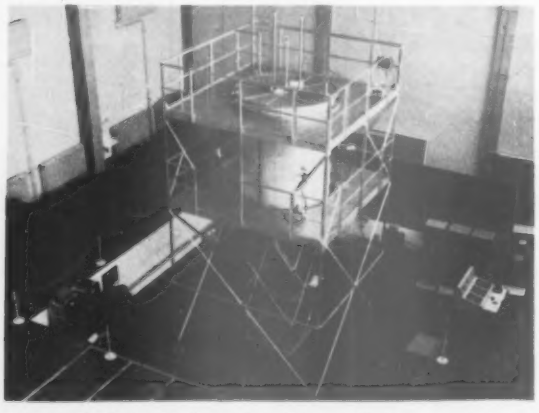


FIG. 1. CRITICAL FACILITY in which accident occurred is unshielded, unreflected aluminum tank fueled with natural-uranium rods and moderated with heavy water

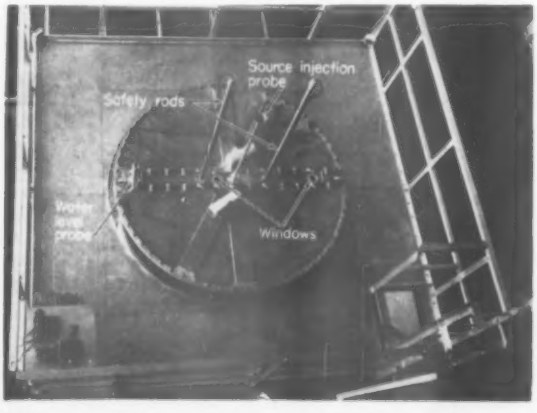


FIG. 2. TANK LID has cadmium safety rods, viewing windows and probe to measure moderator level. Tube at center is for neutron-source insertion

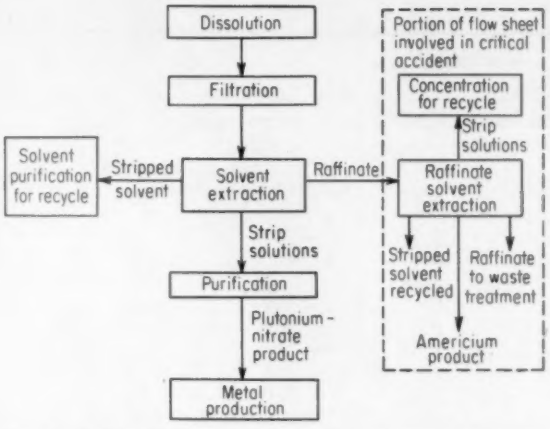


FIG. 1. FLOW SHEET for plant in which accidental criticality occurred. Portion involved is at right

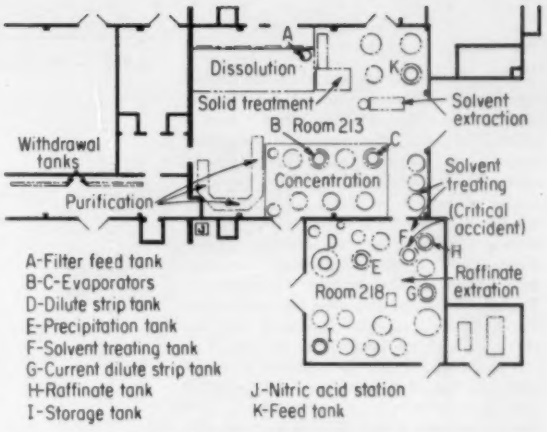


FIG. 2. PLANT LAYOUT shows relation of different processing areas and tanks set to receive near-critical liquids

Los Alamos Criticality Accident, December 30, 1958

By HUGH C. PAXTON, R. D. BAKER, W. J. MARAMAN, and ROY REIDER
Los Alamos Scientific Laboratory, Los Alamos, New Mexico

EDITORS' NOTE: *A sudden criticality in a processing vessel at the Los Alamos plutonium-processing plant occurred on December 30. As a result a technician died 36 hr later (NU, Feb. '59, p. 21).* NUCLEONICS *presents here a report of the official investigation of the accident. The report tells that the accident occurred during an inventory in which normal plant flow was interrupted. An unusual amount of plutonium had collected in a processing tank. When a stirrer was actuated an aqueous solution at the bottom of the tank flowed up around the plutonium-rich organic phase above it, producing criticality.*

THIS NUCLEAR CRITICAL ACCIDENT resulted from an unusual and complex set of circumstances. Reconstruction of the steps that preceded it and analyses of the materials involved now give a reasonably specific picture of the conditions at the time of the radiation burst.

Operational Background

The portion of the plant in which the accident took place is used for concentration and purification of "lean" residues from a plutonium recovery operation. Typically, solutions contain less than 0.1 gm/liter of plutonium and traces of americium. The plutonium and americium are separated by repeated batch extraction into tri-*n*-butyl phosphate (TBP) carried in organic solvent, followed by back extraction into an aqueous phase that is concentrated by evaporation. The resulting solution, containing plutonium at a few grams per liter, then is fed back into an earlier recovery stage.

These processes are complicated by hydrolysis of TBP into mono- and dibutyl phosphates from the actions of heat, nitric acid and alpha-particle radiation. Both hydrolysis products tend to form tightly bound plutonium complexes, and periodically they must be precipitated from the TBP-solvent mixture. These plutonium-rich solids are filtered and sent to another part of the plant for processing in small batches. Figure 1 is a simplified flowsheet for the residue-recovery operation, and Fig. 2 shows the corresponding layout of equipment.

At the time of the accident a physical inventory was in progress in the TBP-solvent-extraction plant. The normal inflow to this area was interrupted, and residual materials in all process vessels were to be evaluated for plutonium content. This requires filtration of solutions supplemented by thorough cleaning of vessels and analyses of clarified solutions and removed solids.

Before the Accident

Reconstruction of significant events indicates that plutonium-rich solids, which normally would have been handled separately, were washed from two other vessels into a large vessel that contained dilute aqueous and organic solutions. After removal of most of the aqueous solution from this vessel, the remaining 40 gal of material was transferred to the stainless-steel solvent-treating tank in which the accident occurred (Fig. 3). This tank already contained about 80 gal of caustic-stabilized aqueous-organic emulsion that had resulted from the second step in the precipitation of TBP hydrolysis products. In addition, 13 gal of concentrated nitric acid was used to wash solids from the bottom of the large vessel into the solvent-treating tank. Transfers into the bottom of the tank were followed by air-sparging, which mixed the contents, so that the emulsion was broken by acidification and plutonium originally in the solids was extracted into the solvent. Phases then separated; about 2.5 min was required.

The resulting situation in the 225-gal, 38-in.-diameter, solvent-treating tank immediately before the accident is now believed to be as illustrated in Fig. 4: 87.4 gal of aqueous solution contained 40 gm of plutonium, and on top, a 42.2-gal layer of solvent contained 3.27 kg of plutonium. Solids (containing 60 gm of plutonium) were suspended in both the aqueous and organic phases and at the interface; few solids settled to the bottom of the tank. Estimates based on Fig. 5, taking into account the tank diameter and effects of neutron poisons, indicate that the 8-in.-thick solvent layer was barely subcritical at the plutonium concentration of 20 gm/liter (the estimated critical thickness is 8¼ inches, and the actual configuration was roughly 5 dollars subcritical).

Continued on next page

The Accident

A chemical operator started the motor driving the stirrer in the solvent-treating tank. There was a "blue flash" and a muffled report. The operator, who was looking into a sight glass at the top of the tank, (Fig. 4) was knocked off the two-step ladder on which he stood. The operator apparently turned the stirrer motor off and then on again (this time noticing a rumbling sound), ran out a nearby exterior door and called that he was "burning up." Though the shock displaced the tank about $\frac{3}{8}$ in. at its supports, the tank was not ruptured and no plutonium escaped.

The tank in which the accident occurred was not bolted to the floor. Tangential shift of one of the supporting legs was apparent because the initial position was outlined by the latest coat of floor paint. Apparently the tank pivoted about the opposite foot.

We cannot be certain that there was no following low-order burst when the stirrer was turned on the second time, but it seems unlikely. No accompanying blue flash was reported, and it is doubtful that the few seconds presumed to have elapsed while the stirrer was off would have been sufficient to re-establish a potentially critical situation. Radiation-detector traces are consistent with a single-burst hypothesis, but do not exclude the possibility of two closely spaced pulses. The stirrer rumbles when turned on under normal conditions; it appears that degree of rumble could easily have been misjudged. We will never know for sure.

At the time of the burst a second operator some 40 ft away in an adjoining room saw a reflection of the light on the walls ("like a photoflash"), heard the report, went to help, and was joined by a third operator. They joined the first operator who had by this time run out of a nearby door. All three men returned past the accident tank to lead the injured operator to a shower. By this time he suspected that he was suffering from an acid burn. As the three passed the tank in which the accident occurred, the second operator turned off the stirrer motor.

The burst activated a radiation alarm located 175 ft away in a nearby building. (This unit was connected to an indicating instrument and set to sound at 10 mr/hr. After a report of the alarm, the entire plant

Continued on page 151

TABLE 1—Pu in Withdrawal Tanks*

	Aqueous solution		*Organic solution*		
Tank no.	*Volume (liters)*	*Pu (gm)*	*Volume (liters)*	*Pu (gm)*	*Solids Pu (gm)*
1	63.5	7.54	0	0	1.33
2	67.2	8.80	0	0	1.09
3†	43.5	3.38	15.8	362	9.89
4	0	0	56.2	1129	7.20
5	0	0	0	0	0
6	68.0	8.02	0	0	1.50
7	54.0	7.07	0	0	0.76
8†	34.7	2.43	25.0	518	18.3
9	0	0	63.0	1263	7.4
10	0	0	0	0	0
TOTALS	330.9	37.2	160.0	3272	47.5
Average concentrations (gm/liter)		0.112		20.4	
Estimated solids not removed from tanks 3 and 8, and other solids					60

* Tanks shown in Fig. 6 are numbered successively from bottom to top. The nearer ones are Tanks 1–5; the farther ones, Tanks 6–10. They were filled from bottom upward.

FIG. 3. ACCIDENT TANK, shown at left, was moved $\frac{3}{8}$ in. by shock that occurred when stirrer was turned on

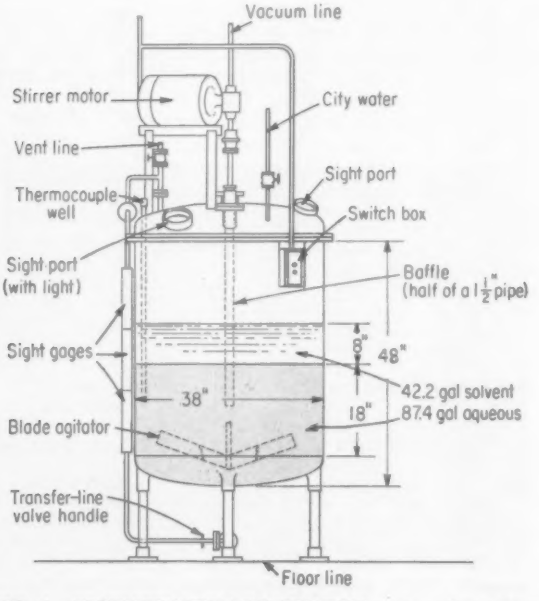
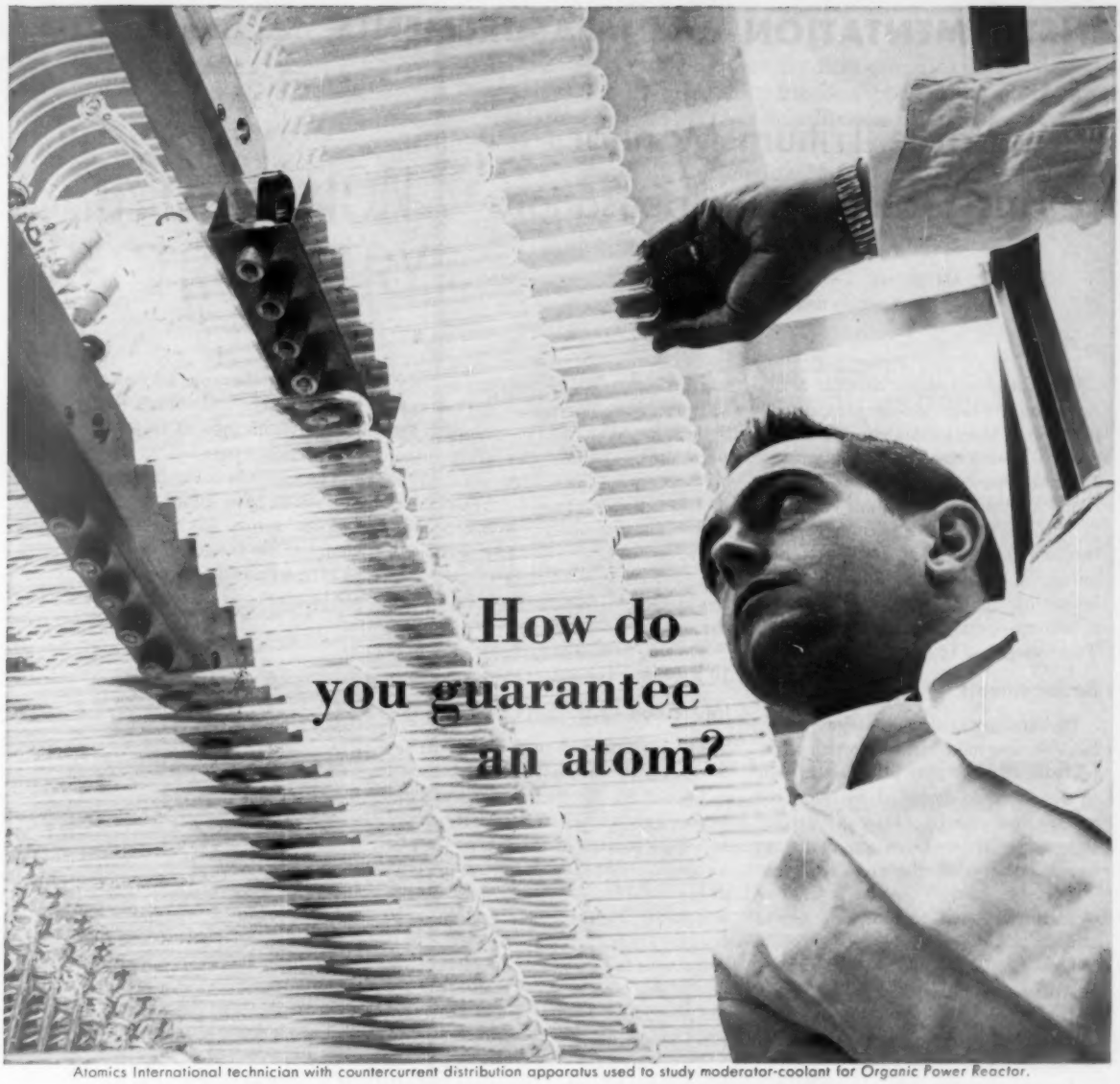


FIG. 4. RECONSTRUCTION OF SITUATION at time of accident indicates tank had barely subcritical layer of organic solution above aqueous layer



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Portable Tritium Monitor Has Gamma Compensation

By J. D. ANTHONY
E. I. du Pont de Nemours and Co., Aiken, South Carolina

Our portable tritium monitor is designed on the same air-sampling principle used in the Los Alamos Model 101 Sniffer (*1*) and the Tracerlab Tritium-Flow Monitor (*2*). But it has an additional gamma-compensation chamber. It accurately detects tritium concentrations in the range 4–1,600 $\times 10^{-6}$ $\mu c/cm^3$. It has a d-c amplifier, two ionization chambers, a deionizer and a battery-operated motor and blower. Total weight is 16 lb.

Requirements

In handling tritium associated with heavy-water moderator there is a possibility that some may become airborne in the form of tritiated hydrogen or water vapor. An instrument is needed to protect personnel from radiation hazard. It is desirable that it be:

- Portable
- Sensitive to 5×10^{-5} $\mu c/cm^3$ of tritium in air
- Linear on all scales
- Able to deionize entering air
- Insensitive to all external radiation
- Equipped with an ion chamber easily decontaminated or replaced.

In our chamber, gamma compensation permits measuring low levels of tritium activity in a gamma field. Air is drawn through a sample chamber, which passes a current proportional to the gamma field and the tritium in the air sample. The compensating chamber is connected so that its current subtracts from the sample-chamber current. The difference current, proportional to tritium activity, is amplified and displayed on the meter. A deionizer is used to trap ions formed before the sample air enters the ion chamber.

The over-all dimensions are $5 \times 10 \times 16$ in. The unit is shown in Fig. 1.

Ionization Chambers

The ionization chambers (Fig. 2) are of Plexiglas. Each has a volume of $\sim$1,600 cm^3. Chamber a is the compensating chamber, and since it can not become contaminated, it need not be removed. Chamber b has an opening at each end for passage of the air being sampled. This chamber is expected to become contaminated and therefore is removable for cleaning or replacement. Chamber c is a spare and is shown without the black conductive coating applied before use.

To connect the conducting walls into the circuit the chambers are plugged into banana jacks mounted on the chassis. The three holes in the top of the ion chambers are for collecting electrodes. Figure 3 shows the chassis compartment into which the ionization chambers are inserted.

The collecting electrodes, mounted in Teflon, have guard rings to reduce leakage across the insulation. Each chamber has three collecting electrodes to give a uniform electric field. They are permanently attached to the chassis and are not disturbed when the chambers are removed or inserted.

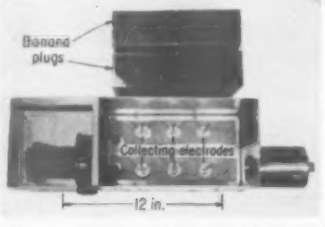

FIG. 3. DISASSEMBLED INSTRUMENT shows collecting electrodes fixed in body, banana plugs for electrical connection to chamber coating

Gamma Compensation

The compensating chamber has a volume equal to the sampling chamber. However, it is closed and measures only gamma radiation. The collecting electrodes of each chamber are connected to the grid of the electrometer tube. The conductive walls are equally and oppositely polarized. Any radiation common to both chambers results in the cancellation of current flow across the high input resistance.

Adjustable volume. Small differences in effective volumes are to be expected in ion chambers designed to avoid costly machining operations. The resulting error is directly proportional to the gamma flux. To correct for this difference our compensating chamber has an inside false wall made of a thin sheet of brass. Moving the

FIG. 1. TRITIUM AIR SAMPLER is sensitive to 4×10^{-5} μ c/cm^3 and has gamma compensation

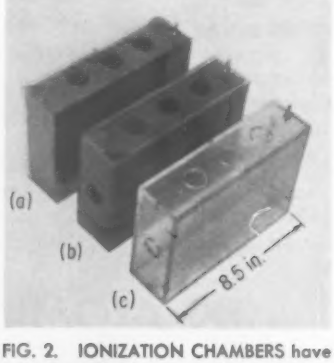

FIG. 2. IONIZATION CHAMBERS have holes for collecting electrodes on narrow sides and holes for air flow at ends. Compensation chamber has closed ends

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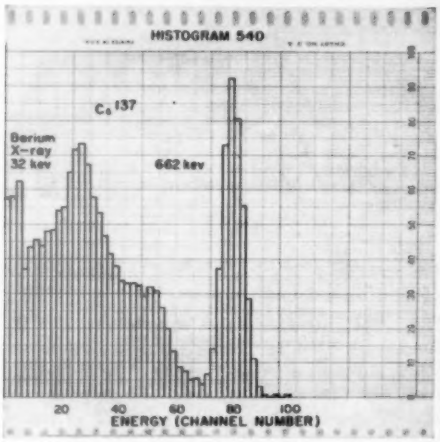

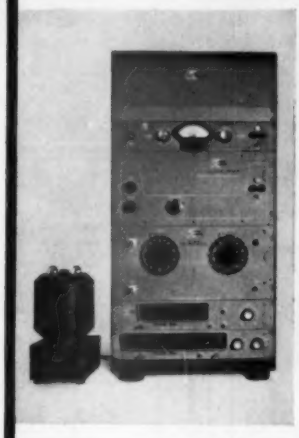

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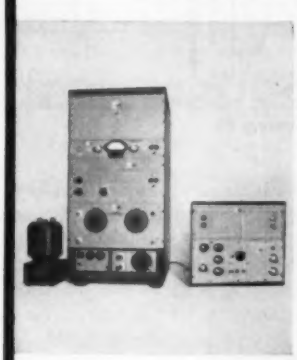

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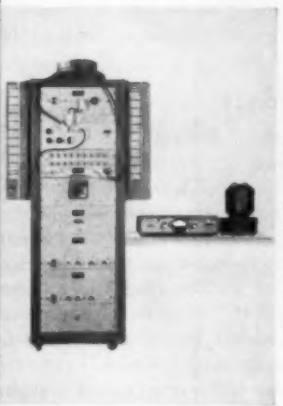

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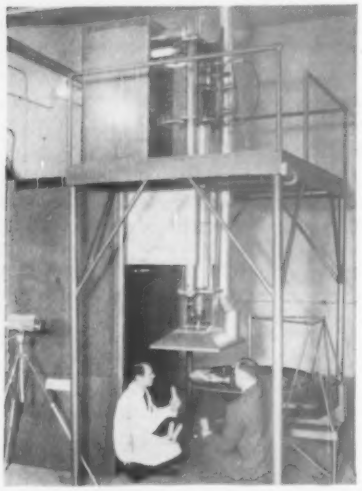

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INSTRUMENTATION AND MEASUREMENTS

This article starts on page 110

brass wall changes the effective volume. The compensating chamber is slightly larger than the sampling chamber to insure that the volume difference will be within the range of adjustment.

Adjustment is made by exposure to a uniform gamma field without removing either chamber. The volumes can be made equal within 1% by adjusting until the meter reads zero. In a uniform field of 10 mr/hr this 1% difference results in an error of $\sim 10^{-5}$ μc/cm³ of tritium. With no compensation the error is 96×10^{-5} μc/cm³. We have no data in nonuniform fields. However, the error would be $\sim 9.6 \times 10^{-5}$ μc/cm³ if there were a difference of 1 mr/hr in the radiation fields at the two chambers.

Deionizer

Since we want to collect only ions caused by tritium beta radiation within the chamber, a deionizer is provided to remove as many ions as possible from the air before it enters. Large charged particles such as those in cigarette smoke are not efficiently collected by either the deionizer or the measuring chamber. Therefore the instrument reading is not seriously affected by smoke unless it is present in such large concentrations that it is easily visible.

The deionizer is housed in an aluminum cylinder attached to the front of the instrument. It consists of positive and negative electrodes supplied by eight 22½-volt batteries in series. Figure 4 shows the construction.

Electronics

The amplifier is the same as that used in the Samson alpha survey meter (*3*) with minor modifications. This amplifier was chosen for its stability, linearity, and high current gain. It is a three-stage-d-c amplifier in which the input tube serves as an electrometer. The circuit employs 100% negative feedback for stability and has a current gain of $\sim 10^8$. The amplifier is linear over the range used and has a drift rate of 8% of the ×10 scale in the first hour after a 3-min warmup. The circuit is shown in Fig. 5.

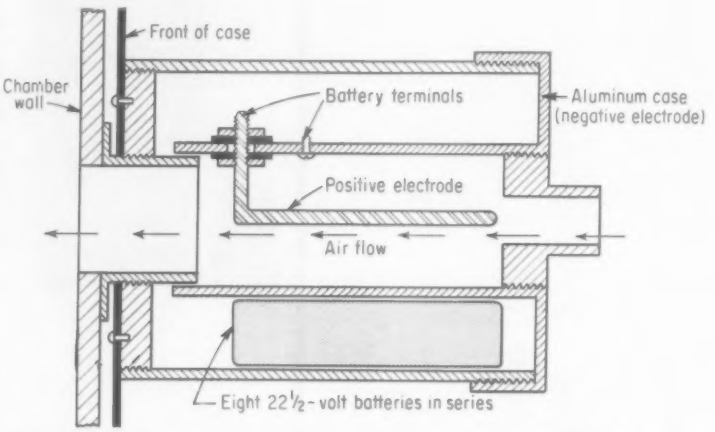


FIG. 4. DEIONIZER uses potential from 8 22½-volt batteries to remove ions from entering air

A-c noise developed in the amplifier is reduced by the capacitor in parallel with the input resistor. The capacitor counteracts the shunting effect of the input capacitance on a-c feedback. This capacitor is a coating of conductive paint on the glass case of the input resistor. When it is not present, circuit noise causes meter fluctuations as great as 40 μa; with it these are reduced to less than 3μa.

Motor and Blower

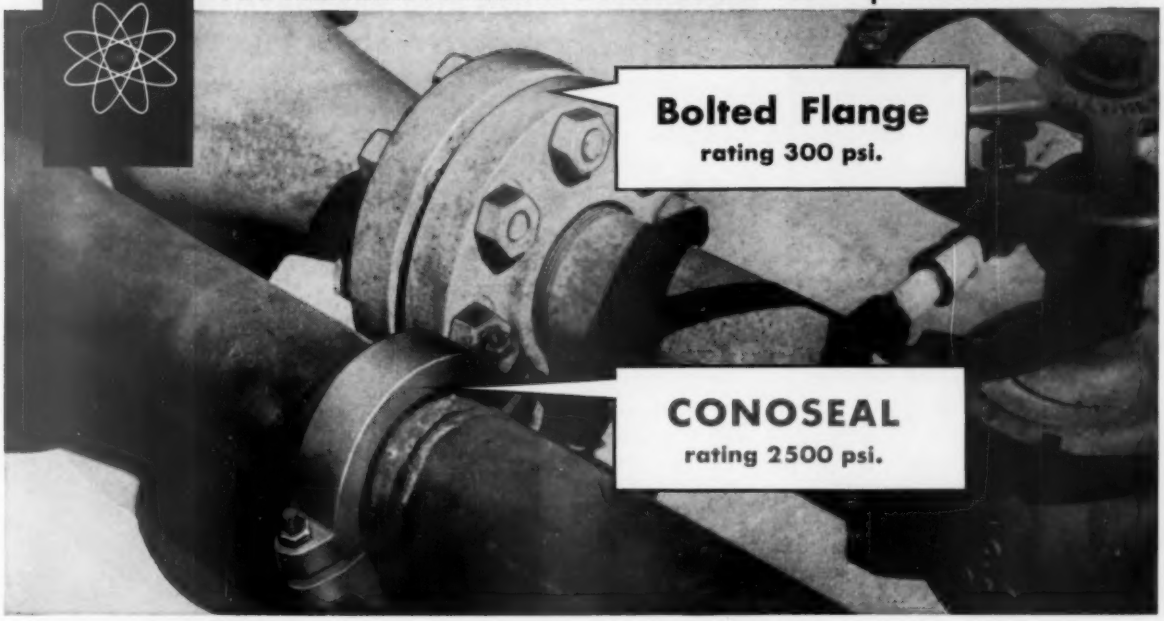
The motor and blower are housed in the bottom of the instrument. The motor is operated from two six-volt batteries in parallel and has a continuous operation time of about 20 hr on one set of batteries. Battery life is much greater in ordinary use when the motor is not normally run continuously. Air flow through the chamber is between 0.75 and 3.3 cfm. Batteries are accessible through the rear.

Calibration

To determine whether the instrument would respond to tritium as

See Marman Products at the Atom Fair

Booth 708, Public Auditorium in Cleveland, Ohio, April 5-10



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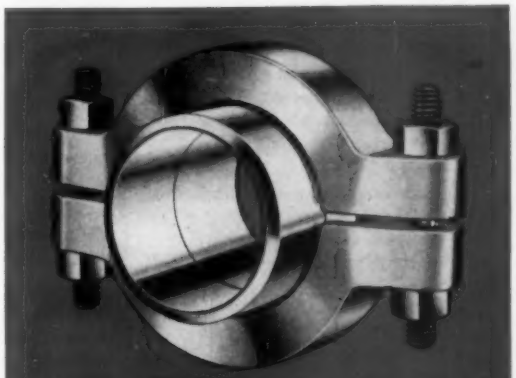

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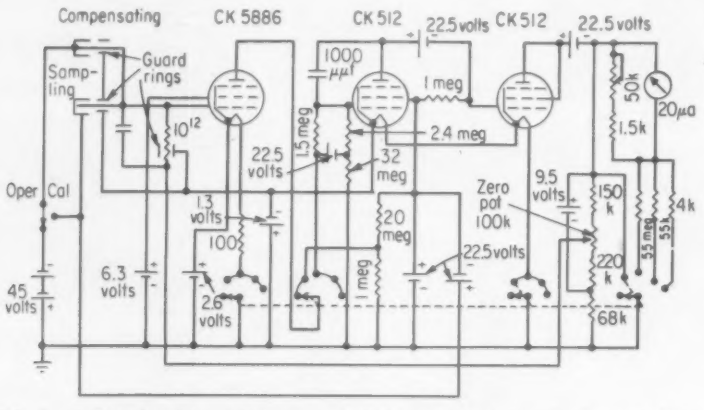

FIG. 5. D-C AMPLIFIER uses 3 stages and 100% negative feedback to get stability, linearity and current gain of 10^8

expected an experimental arrangement was set up as shown in Fig. 6. The portable sampler was connected in series with a 60-liter box in a closed system. Tritium was introduced as vaporized HTO by first drying the air in the box with silica gel and then placing a tray containing a solution of liquid HTO in the box. After enough tritium oxide had evaporated to give the desired concentration, the tray was removed. The air was then circulated continually by the instrument blower to give uniform concentration throughout. Lower concentrations were obtained by disconnecting the tubing at one point for a short time to allow contaminated air in the system to become diluted.

A standard Applied Physics Corp. chamber connected to a calibrated vibrating-reed electrometer measured the tritium in the sample. All of the readings of the portable tritium air sampler and the vibrating-reed electrometer agree within ±25%, which is estimated to be the accuracy of the air-sampling method that is employed.

Routine calibration. Provision is included in the portable tritium air sampler to use a gamma source for calibration, since routine calibration using tritium is impractical. A switch is provided which eliminates gamma-compensating during calibration and places the two chambers in parallel.

A simple calculation determines the gamma equivalent of tritium beta radiation. A field of 1 mr/hr causes the same current in one chamber as 9.61×10^{-5} μc/cm³ of tritium. Because two chambers are used in calibrating and only one in detecting tritium, 1 mr/hr of gamma radiation gives a reading equal to $2 \times 9.61 \times 10^{-5} = 19.22 \times 10^{-5}$ μc/cm³ of tritium.

Because the characteristics of some of the circuit components may change with use the sampler should be recalibrated every 2 weeks.

* * *

This article is based on work under Contract AT(07-2)-1 with the AEC.

BIBLIOGRAPHY

1. B. C. Eutaler et al, LA-1909 (April, 1955)
2. J. Brinkerhoff, C. A. Ziegler, R. Bersin, D. J. Chleck, NUCLEONICS **17**, No. 2, 76 (1959)
3. Operating instructions—Samson alpha survey meter. (Radioactive Products, Inc., Ferndale, Mich.)

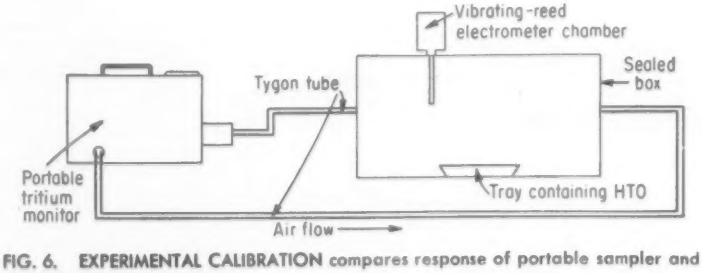

FIG. 6. EXPERIMENTAL CALIBRATION compares response of portable sampler and vibrating-reed static sampler

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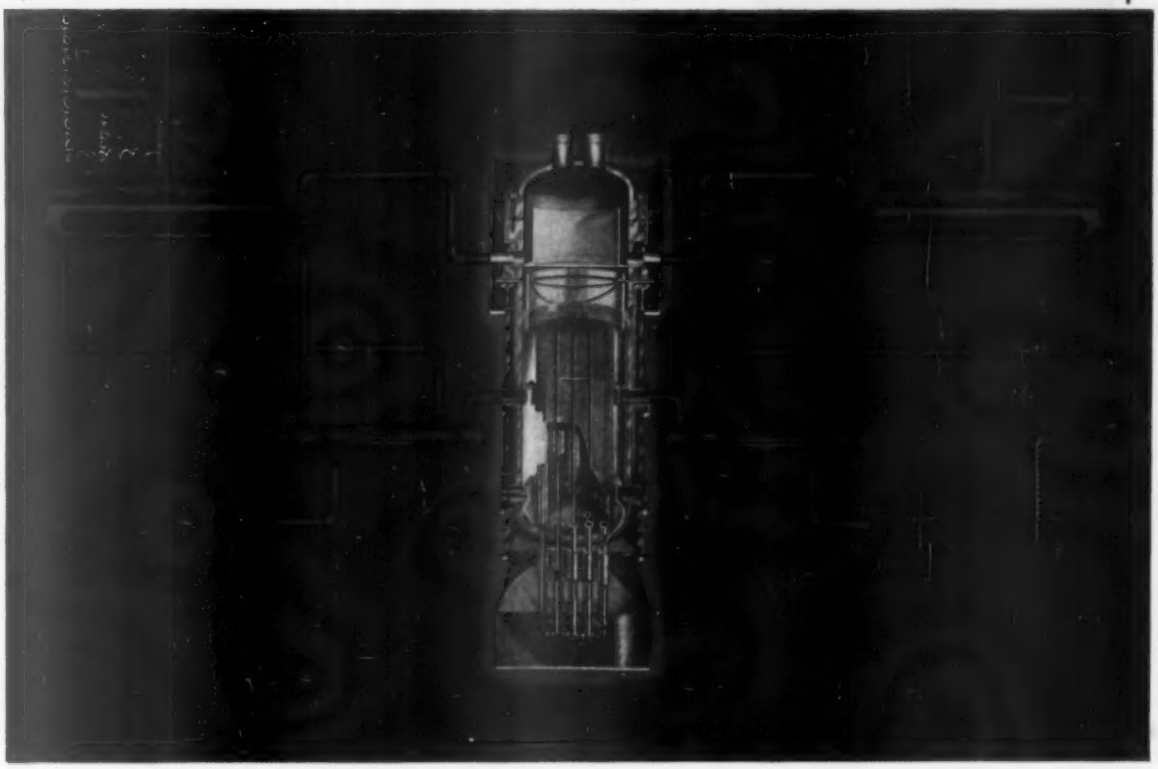

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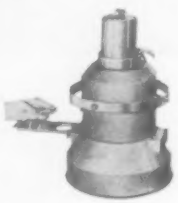

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Coated Semiconductor Is Tiny Neutron Detector

By R. V. BABCOCK, R. E. DAVIS, S. L. RUBY, K. H. SUN and E. D. WOLLEY
Westinghouse Electric Corporation, Pittsburgh, Pennsylvania

Semiconductor neutron detectors less than $\frac{1}{10}$ in. in diameter can measure fast and thermal neutron fluxes in the range 10^4–10^{11} n/cm²/sec. There is adequate discrimination against associated gamma radiation. We have used the detectors to map the thermal-neutron-flux pattern in a low-power reactor core. Figure 1 shows one of the detectors.

The detector consists of a *pn* junction coated with a nuclide that produces energetic charged particles from neutron irradiation. For fast neutrons we surround the system with paraffin to provide proton recoils. Dimensions are small; the semiconductor element measures ~1 mm on an edge. For this reason spatial resolution rivaling foil techniques is available at considerably less time and effort. Radiation damage may be a problem, but in one test an exposure corresponding to 5×10^9 fission fragments/cm² produced no change in counting efficiency.

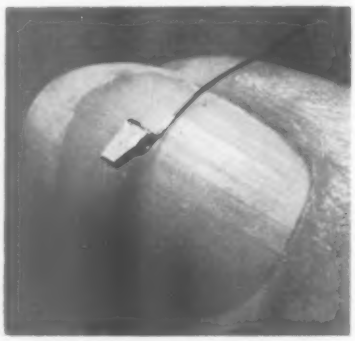

FIG. 1. NEUTRON DETECTOR ON THUMBNAIL. It offers spatial resolution equivalent to foil techniques at less cost and effort

Prospects

With these detectors measurements of time-varying fluxes are practical in many otherwise intractable situations. Low gamma sensitivity and small flux perturbation recommend the devices particularly for reactor experiments. In other areas there is the prospect of a "long counter" with no thermal sensitivity.

The attractive size carries a penalty of relatively low counting efficiency, ranging at present from 10^{-4} to 10^{-7} count/n/cm². A size limitation is fixed by relatively large capacitance per unit area of a *pn* junction and also the noise level of the amplifiers. Appropriate control of the junction thickness will lead to lower capacitance. Operation with reverse bias can also increase signal size. Our expectation is that devices of this size can be built with efficiencies of 10^{-3} count per unit flux.

As yet little effort has been spent on the problem of rise time. For alpha particles, which are stopped within a few microns of the junction, rise times are less than 2×10^{-8} sec (*1*). We feel that rise time t is related to length of the particle track L as $t = L^2/D$, where D is carrier-diffusion constant. Present limits in counting rates are set by external circuitry.

Semiconductor Detection

The ability of semiconductor junctions to detect charged particles has been demonstrated by various workers (*1*, *2*). A charged particle passing through a semiconductor loses energy by creating electron-hole (e-h) pairs, which diffuse through the material until they either recombine or are removed by some other mechanism. If these e-h pairs diffuse into the *pn* junction, they are separated by the field within the junction and produce a voltage pulse that can be amplified and counted. If the incoming particle is an alpha particle, triton or fission fragment, a suitably designed junction will collect all of the e-h pairs, usually in less than 10^{-7} sec. This forms a voltage pulse approximately equal to the particle energy divided by the ionization potential of the semiconductor and the capacitance of the junction. However, a gamma photon provides such low ionization density that only a small fraction of its energy is dissipated in the range of the junction. Consequently, pulse-height

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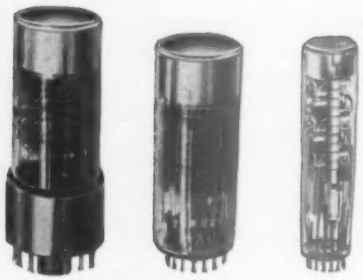

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INSTRUMENTATION AND MEASUREMENTS

This article starts on page 116

discrimination against gamma fluxes is adequate except for pile-up phenomena encountered in extremely high fluxes.

Neutrons are commonly detected through charged particles from their nuclear reactions. For fast neutrons appropriate reactions are recoil of protons, fast fission of Th^{232}, Np^{237}, U^{238}, and $N^{14}(n,p)C^{14}$, $S^{32}(n,p)P^{32}$, $Li^6(n,\alpha)H^3$. For thermal neutrons appropriate reactions are thermal fission of U^{235}, U^{233}, Pu^{239}, $B^{10}(n,\alpha)Li^7$, and $Li^6(n,\alpha)H^3$. A *pn* surface junction coated with a thin layer containing one of these nuclides makes a simple neutron detector. A schematic of such a device is shown in Fig. 2.

In this way, we have developed silicon and germanium junction detectors suitable for measurement of thermal and fast neutron fluxes, using H^1, Li^6, B^{10} and U^{235} as target nuclei. By varying the junction areas and the nature and amount of target nuclei, these detectors can be adapted to various neutron-flux measurements in the range 10^4–10^{11} n/cm²/sec. Dabbs and his coworkers have used similar techniques to measure U^{233} fission spectra at liquid-helium temperatures (*3*). By forming broadly graded junctions that do not operate at room temperatures but provide low capacitance per unit area at low temperature, Dabbs was able to use junction areas greater than 1 cm² with correspondingly higher sensitivity.

Ge Thermal Detectors

Surface *pn* junctions were formed from *p*-type germanium by diffusion techniques. We diced the units and

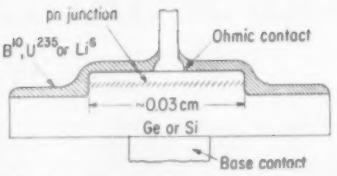


FIG. 2. CROSS SECTION shows how neutron-sensitive nuclide is coated above pn junction on germanium or silicon wafer

made circular junction areas of about 3×10^{-3} cm². B^{10} layers were deposited on the *n*-type surface and contacts soldered. We made six units and tested them in a thermal neutron flux of 3×10^6 n/cm²/sec, obtained from a Van de Graaff generator with the $Be^9(d,n)B^{10}$ reaction. The neutron flux was determined by indium-foil activation with cadmium-difference techniques.

We use a 10,000-ohm load resistor across the leads from the detector and no bias. Signals are connected directly to an a-c-coupled pulse-amplification system with 5-Mc bandwidth, a single-channel pulse-height analyzer, and a scaler. In practice, the amplification was achieved by using a wide band preamplifier with a gain of 100 in front of the usual nuclear-detection amplifier.

In Fig. 3, representative experimental pulse-height spectra are compared with spectra calculated from range and differential-cross-section data. The maximum pulse heights were about 300 μv. Large counting rates at low pulse height are attributed to the partial collection of e-h pairs formed by particles incident just outside the junction area. The response to a Co^{60} gamma flux of 10^9 photons/cm²/sec is

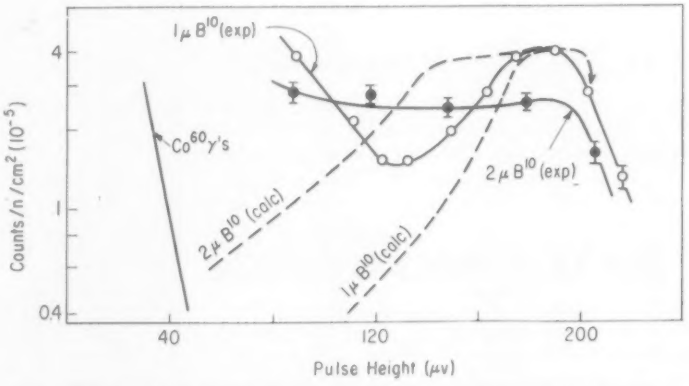
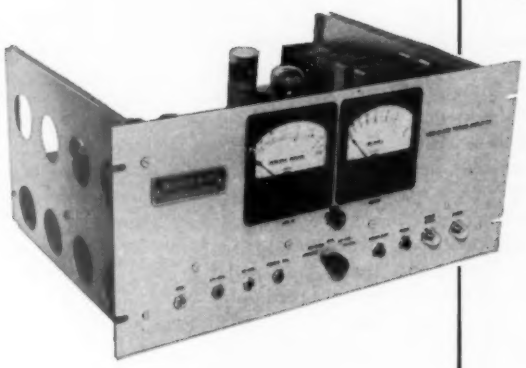


FIG. 3. PULSE-HEIGHT SPECTRA—calculated and measured—for B^{10}-coated detectors and response to Co^{60} flux at 10^9 photons/cm²/sec. Window width was 30 μv

AMPLIFIERS for nuclear reactor control



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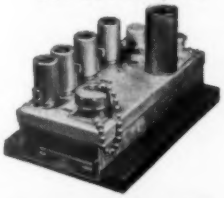

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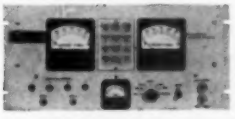

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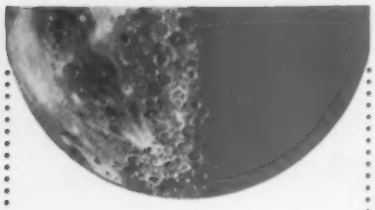

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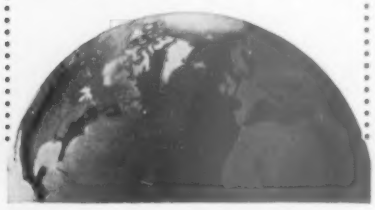

INSTRUMENTATION AND MEASUREMENTS

This article starts on page 116

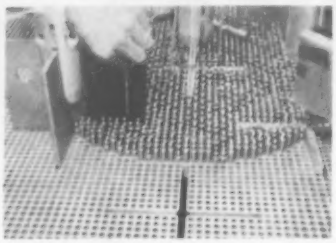

FIG. 4. MEASURING REACTOR FLUX, miniature detector goes among fuel elements of critical facility

also shown in Fig. 3, indicating that excellent discrimination against gamma flux is achieved by appropriate pulse-height biasing.

Primary consideration in the application of these detectors is their sensitivity to damage by fast neutrons and alpha particles from the B^{10}. Recent fast-neutron damage studies on germanium (*4, 5*) indicate a useful life of the order of 10^{13} nvt. The lifetime in terms of alpha-particle dose was measured by exposing an uncoated detector to 5-Mev radium alpha particles. A total dose of 3×10^{11} alphas/cm², corresponding to a thermal-neutron dose of 10^{13} nvt, decreased the counting efficiency above a fixed pulse-height bias by 15%. This result provides an upper limit for the damage rate due to the less energetic alpha particles from the $B^{10}(n,\alpha)Li^7$ reaction.

Si Thermal Detectors

Silicon *pn* junctions with depth and capacitance per unit area roughly equal to those of the germanium junctions were also obtained. We cut rectangular wafers, a few square millimeters in area, and coated them with $U^{235}O_3$ powder. They were then connected to 0.080-in.-diameter coaxial cable and sealed in 0.093-in.-diameter aluminum tubing. Counting efficiencies of these detectors were in proportion to the U^{235}-coated area, ranging from 10^{-7} to 10^{-6} counts/n/cm² over 14 such detectors. Maximum fission pulse heights ranged from 1 to 5 mv, in inverse proportion to the junction area. Pulses due to alpha disintegration of the U^{235} of about $\frac{1}{20}$ this size also appeared, demonstrating the linear energy conversion of the devices. Because of the relatively large particle energy and correspondingly large signal these detectors can drive standard pulse-counting equipment through up to 100 ft of transmission cable. Incidentally, if it is desirable, such signals can be analyzed without additional preamplification.

With these detectors, axial and horizontal neutron flux distributions were measured in a cylindrically symmetric critical-experiments reactor at the Westinghouse Reactor Evaluation Center. A photograph of one detector being inserted into the reactor core is shown in Fig. 4. The resulting horizontal flux profile is compared in Fig. 5 with a suitably normalized Bessel function. Flux variation due to periodic arrangement of fuel elements shows the dimensional resolution possible with these detectors.

This information was obtained in directly usable form during 21 min of reactor operation. The unnormalized flux values were consistent with simultaneous indium- and gold-foil activation measurements. The corresponding axial flux profile, obtained during operation at a lower power level, is shown in Fig. 6. The solid curve is a cosine curve normalized at the maximum.

Studies of fast-neutron damage to thin-base silicon diodes show serious increases in the forward voltage drop and reverse current after a total fast-neutron exposure of 10^{15} nvt (*6*). Although these parameters are not direct indicators of charge-separation efficiency, it is expected that properly de-

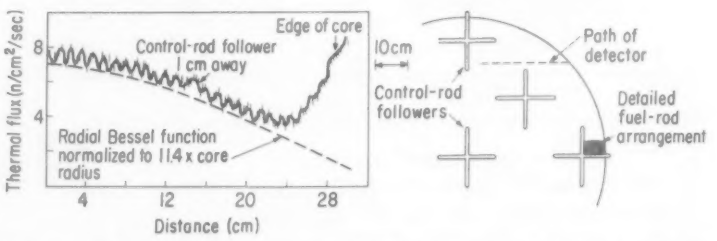

FIG. 5. CORE AND FLUX observed in it with miniature detector. Radial profile fits appropiate Bessel function except for variations corresponding to fuel-rod spacings

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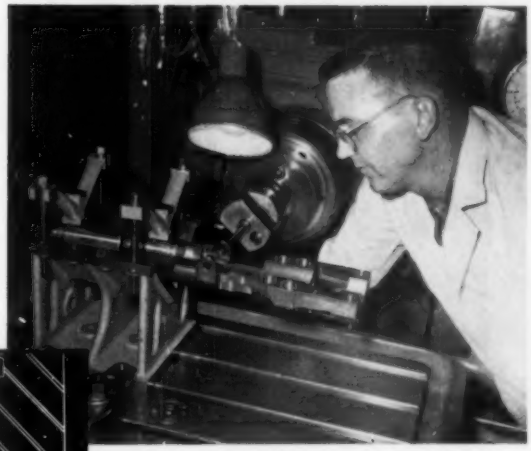

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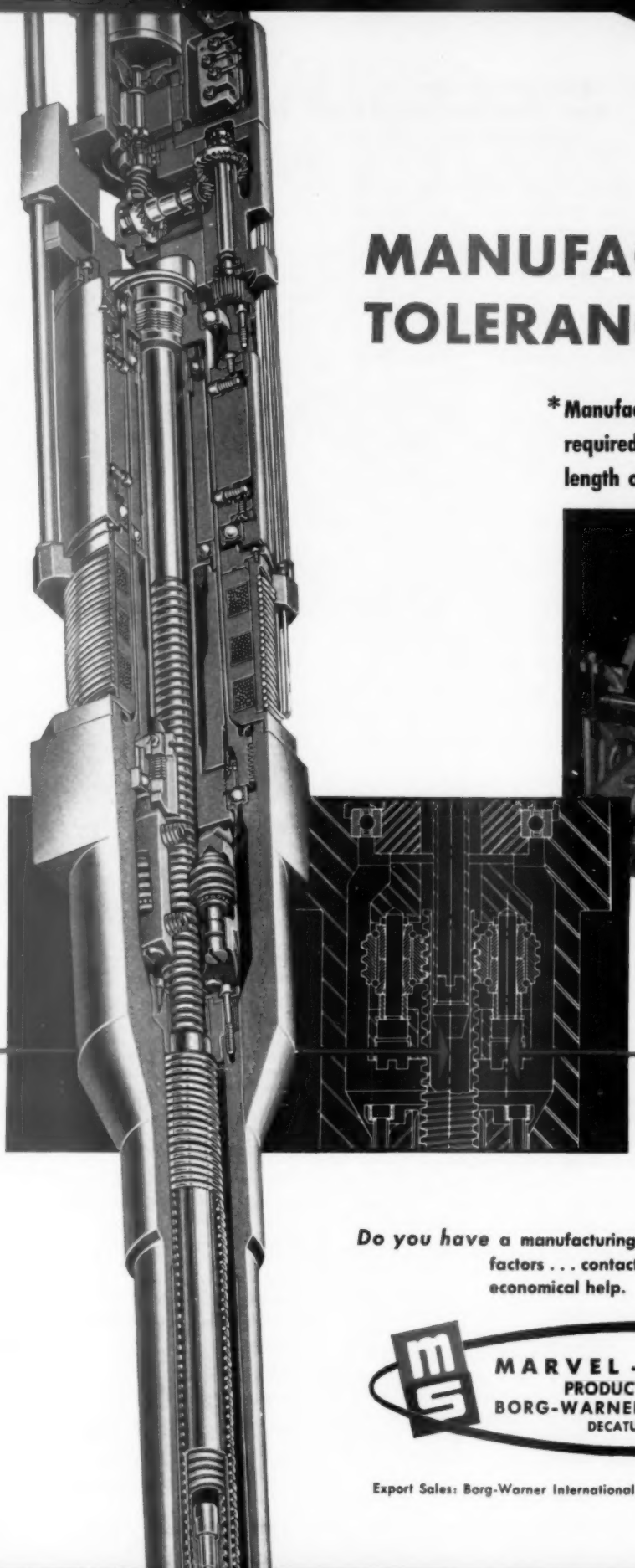

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ALIANYIC 239

This article starts on page 116

signed particle detectors should operate to this level or better. The damage due to fission fragments from the U^{235} coating must also be considered. In a crude damage experiment one U^{235}-coated detector, exposed to an integrated reactor flux of 10^{14} nvt thermal neutrons, corresponding to $\sim 5 \times 10^9$ fission fragments/cm², showed no change in counting efficiency.

Because fission-fragment damage was expected to be the controlling damage effect, a similar silicon detector was made with a junction of 5×10^{-3} cm² area and coated with less than 1 mg/cm² of Li^6F. This detector provided pulses of 150 μv and counting efficiency of 3×10^{-6} counts per unit flux. Since the range of the 2.8-Mev triton is about 8 mg/cm², the counting efficiency could be increased by a factor of 10 by using a thicker Li^6F coating.

Fast-Neutron Detectors

Placing 1-mm paraffin layers over detectors made by the previously outlined procedures, we made fast-neutron detectors. Fast-neutron pulses of up to 1 mv, corresponding to about 2 Mev in the junctions, were observed from a $Be^9(d,n)B^{10}$ neutron source. This maximum energy output of 2 Mev in response to a neutron flux containing energies up to 6 Mev may indicate that the range of the recoiling protons was too long to permit complete collection of the e-h pairs. Such a saturation phenomenon should not affect counting efficiency. Observed counting efficiencies for a collimated neutron beam were about 3×10^{-6} counts/n/cm² above a pulse-height bias corresponding to 1 Mev. Corresponding efficiency in an isotropic flux would be just ¼ as great because of the additional likelihood that recoil protons will be directed away from the semiconductor.

Counting efficiency as a function of energy has not yet been measured. However, this can be estimated from the probability of a recoiling proton escaping the paraffin layer and entering the semiconductor with a certain minimum energy. Detailed consideration of the differential cross section for neutron-proton scattering, and proton range-energy relations in paraffin indicate a nearly linear increase in counting efficiency with incident neutron energy for a thick paraffin layer. By appropriate variation of the amount of paraffin at different heights above the junction the counting efficiency could be made independent of neutron energy above a certain threshold. The result will be a cone-shaped paraffin layer. Thus one could hope to make a miniature "long counter," or energy-independent counter, with no thermal-neutron sensitivity and very little flux-perturbing effect.

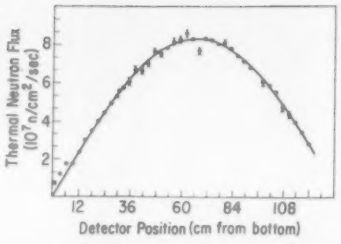

FIG. 6. AXIAL FLUX PROFILE in same reactor matches normalized cosine function

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5. S. L. Ruby, F. D. Schupp, L. D. Wolley, *Phys. Rev.* **112,** 1493 (1958); Schupp, Ruby. Effect of monoenergetic, fast neutrons on N-type Ge, Westinghouse Electric Corp. Report
6. S. A. Yefsky, M. A. Xavier. Performance and predictability of semiconductor diodes and rectifiers exposed to nuclear radiation, Inland Testing Lab. Report (1957)

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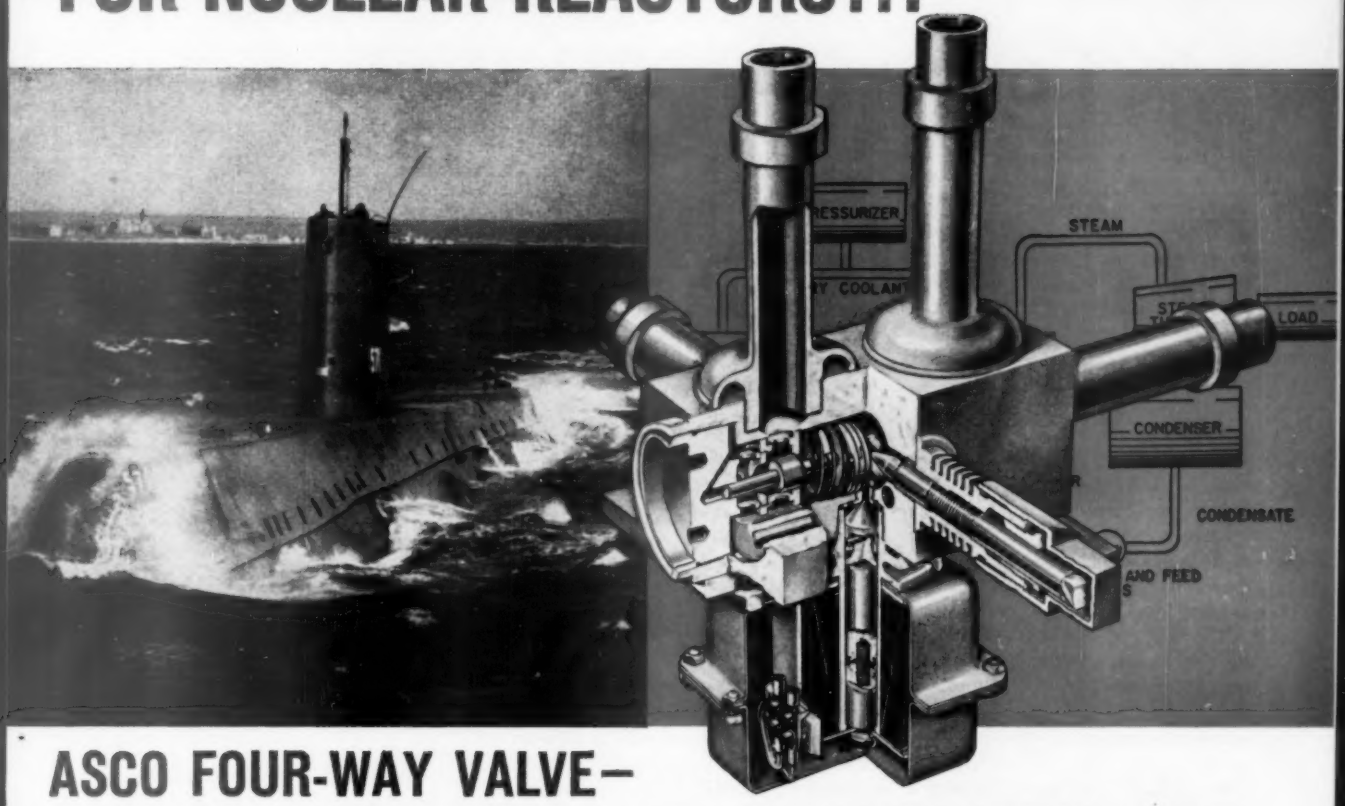

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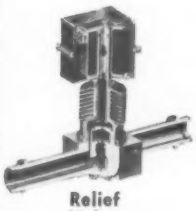
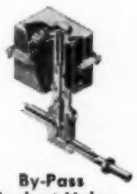


Relief Valve



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2-way Valves

3-way Valves

Instrumentation Control

2-way Valves

3-way Valves

Gamma Spectrometric Assay of Fission-Product Kr^{85}

By H. W. ALTER
Vallecitos Atomic Laboratory, General Electric Company
Pleasanton, California

Gamma spectrometry has proved to be better than beta counting for Kr^{85} assay in short-cooled irradiated fuel samples. The method is relatively free from interference by other fission-product gases and is rapid, precise and readily adaptable to routine assay.

Assay of noble-gas fission products is an important indication of the integrity of nuclear-fuel cladding and of the properties of the fuel. In principle, a volumetric determination of the total fission gas would yield satisfactory results, but in practice the requirements of high sensitivity and simplicity force the use of radioactive counting techniques. Of some thirty-three noble-gas fission-product nuclides, only six radionuclides have half-lives >4 hr.

The long half-life of Kr^{85} (10.3 yr), with attendant freedom from saturation at extended exposures and continued presence at long cooling times, makes it a logical choice for assay. In addition, its relatively high-energy gamma (0.52 Mev) makes it particularly suitable for gamma spectrometry.

Beta counting has been the conventional method for Kr^{85} assay.* The method has high sensitivity and adequate precision under the proper conditions. The presence of other noble-gas beta activities will, however, yield high results with gross beta counting at cooling times less than 60–90 days. Thus 5.27-day Xe^{133} activity will still comprise 65% of the Kr^{85} activity at 60 days. Although some discrimination against Xe^{133} is possible through the use of absorbers, a severe cooling-time limitation exists. This is a disadvantage in fuel-development programs where rapid data collection is desired.

With NaK as coolant in capsule fuel experiments, another source of interference is A^{39} produced by the (n,p) reaction in K^{39}. Argon-39 is a pure beta emitter, having a 260-yr half-life and a 0.57-Mev beta. Thus, it cannot be distinguished from Kr^{85} by beta counting. In fact it was the A^{39} difficulty that prompted this study of Kr^{85} gamma counting.

The 0.52-Mev Kr^{85} gamma occurs in only 0.65% of the disintegrations. While gross gamma counting of a sample of Kr^{85} and A^{39} would effectively discriminate against A^{39}, gamma activities from other noble-gas nuclides are dominant even at long cooling times, e.g., Xe^{131m}, Xe^{133} and Xe^{133m}.

Fortunately, the energy of the Kr^{85} gamma is higher than any others present after 5–10 days. Together with absorbers that remove the large bulk of low-energy gammas and bremsstrahlen, gamma spectrometry offers a solution to the problem of Kr^{85} assay at such short cooling times even in the presence of interfering nuclides.

Spectrometer Setup

An RCL 256-channel pulse-height analyzer was used in conjunction with a 3-in. solid sodium iodide crystal. For counting purposes, the Kr^{85} photopeak was spread over 10–15 channels. Measurements could be made of the peak height from an automatic plot of the spectrum or by direct readout of all the channels involved. Activity ratios based on either peak height or readout were in good agreement.

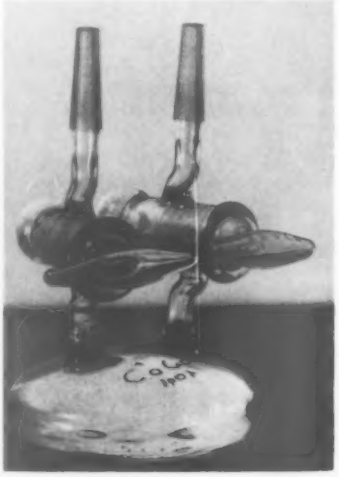

FIG. 1. Pyrex gas-counting cell used in Kr^{85} gamma spectrometry. Three cells were fabricated with volumes in the range 53–66 cm^3. Two stopcocks are provided for experimental purposes; only one is needed in routine use

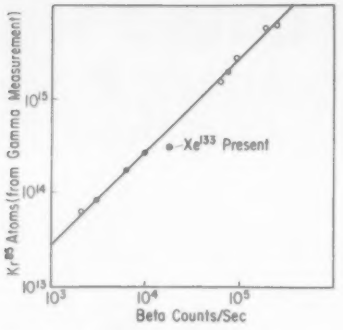

FIG. 2. Comparison of beta and gamma counting of Kr^{85}. Good linearity shows suitability of gamma spectrometry. Point off the line is from sample containing significant quantities of Xe nuclides; it illustrates error introduced in Kr^{85} beta counting by other noble gases while effect on gamma counting is negligible

The gas-counting cell (Fig. 1) was placed on the end of the 3-in. crystal with $\frac{2}{16}$-in. lead absorbers when counting Kr^{85} samples containing Xe. No end shielding was provided for the crystal, and background in all the photopeak channels was 130–160 cpm.

Calibration and Assay

A sample of Kr^{85} standardized by absolute beta counting* was placed successively in each of three counting cells ranging in volume from 55 to 63 cm^3. The relative gamma counts thus obtained were used for cell-geometry correction factors. The sample was retained permanently in one of the cells as a relative standard.

A counting efficiency of 12.3% was obtained for Kr^{85} gammas. The limit of sensitivity was about 10^{12} Kr^{85} atoms. Higher sensitivities are possible with different cell-crystal geometries.

In routine assay, an aliquot portion of the unknown sample was counted followed by the standard sample. The ratio of counts, together with the cell factor and aliquoting factor, gave the atoms of Kr^{85} in the unknown.

An assay of this type was made on a number of samples on which beta end-window counting had also been performed with another apparatus. The results are given in Fig. 2. The ratio of Kr^{85} atoms per beta count per second shows an average deviation of 6% over a 100-fold range, well within the expected experimental uncertainty.

* M. Reynolds, NUCLEONICS **13**, No. 5, 54 (1955). R. B. Regier, Abstract No. 7, Division of Analytical Chemistry, 133rd Meeting ACS (1958).

* We are indebted to Dr. Floyd Momyer of the University of California Radiation Laboratory for this standardization.

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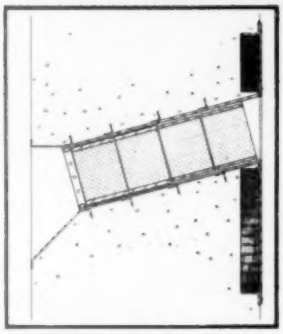
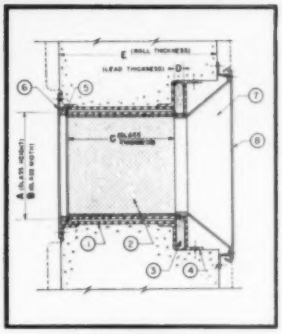
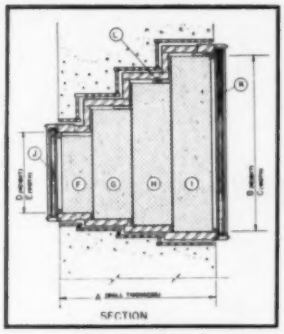


Concentrated Area viewing



Wide Range viewing



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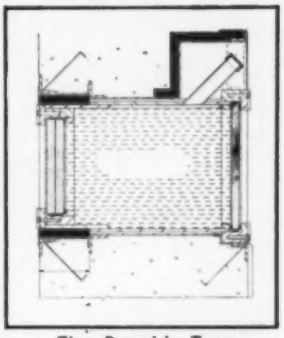

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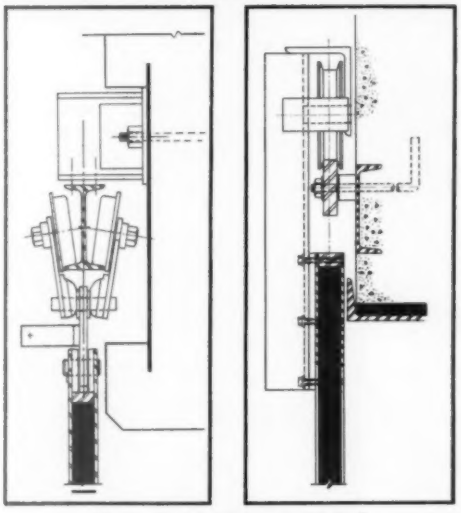

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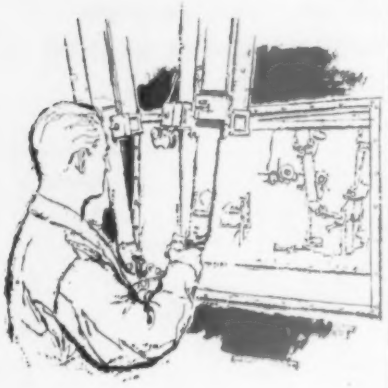

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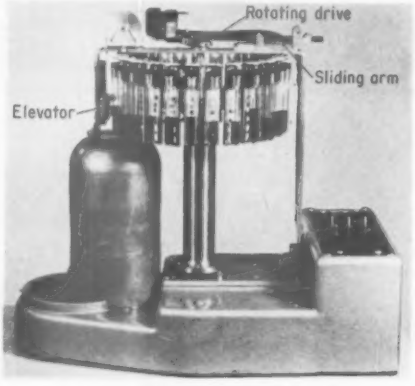
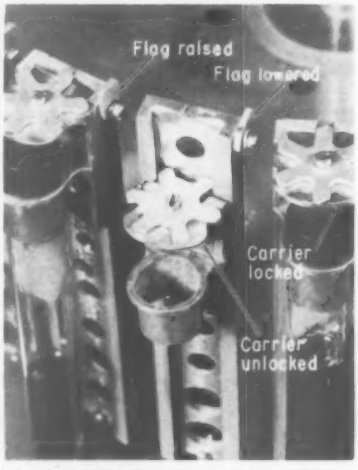
Simple Liquid-Sample Changer

By NATHAN B. FRUCHTER, *Veterans Administration Hospital*
Long Beach, California

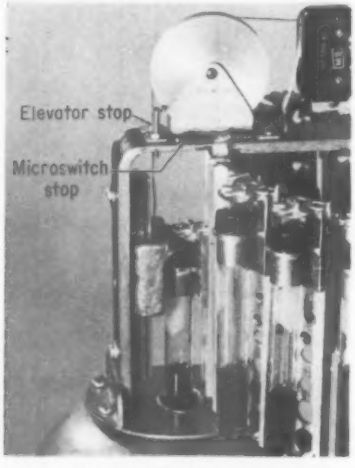


AUTOMATIC LIQUID SAMPLE CHANGER is adaptation of Tracerlab Automatic Planchet Changer SC-6. Turntable was raised, stop and jam switches relocated, latching arrangement reinforced. Sliding arm that formerly moved planchets now raises and lowers sample elevators

BEFORE MODIFICATION instrument has turntable holding planchets at rim. Sliding arm pushes sample into shielded detector housing, counting sequence occurs, printer records results, and turntable moves to put next sample in position



SAMPLE HOLDERS are locked in raised position by six-tooth wheel except when elevator engagement raises holder slightly and turns wheel to unlocked position. Raised flag on occupied sample holder moves Microswitch stop into activation position when that holder reaches elevator. (Spring-loaded locks have recently replaced toothed wheels.)



LEAD-LOADED ELEVATOR rises and falls in response to cable that runs over wheel and back to sliding arm. Raised flag puts Microswitch stop in position to hit switch when loaded carrier reaches elevator, and closing of Microswitch starts automatic counting cycle. Simple device is both inexpensive and satisfactory. Basic program is unchanged

Core Designs Evaluated at WTR

The Critical Experiment Station, part of the WTR facility, has been in use to evaluate the core design and to gather operating data for the Testing Reactor. CES is one of two WTR critical facilities now available to industry for low-level irradiations, for testing criticality, temperature coefficients and other core parameters.

The WTR core support will be installed in April, and the reactor is scheduled to go critical in May. It will be available to industry and university laboratories shortly thereafter at an initial power level of 20-mw. Available services will include: high-flux irradiation space; high-temperature, high-pressure loop equipment; hot cells; critical experiment; gamma irradiation.

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Gaskets for Reactor-Plant Service

Gasketed closures for sealing primary-system components in pressurized-water reactors have long represented a potential area for improvement in plant-maintenance procedures and cost reduction. To date, limited use of gaskets has been made because of two uncertainties: (a) the allowable amount of leakage of primary-system water and (b) the expected amount of leakage of a particular style of gasket.

To determine the expected leakage, the Bettis Plant of Westinghouse conducted a review of the literature and constructed a special loop (at the Crane Co.) to test gasketed closures at 600° F and 2,000 psia. In addition, some closures at Bettis were instrumented to obtain actual leakage data. Following are some of the most significant results of the tests and survey.

Threaded Joints

The threaded-joint type of closure accounts for ~100 potential applications in a small-size reactor plant—small closures (up to 2 in. o.d.) such as manually capped valves and vents. It usually takes the form of a cap or plug threaded into or on a body with the gasket trapped between them.

A gasket-leakage test program conducted with a representative closure of this type indicates that the most acceptable style of gasket is the hollow stainless-steel O-ring. In a preliminary evaluation of six gasket styles (flat copper, flat nickel, stainless-steel O-ring, silicone O-ring, stainless-steel-wound asbestos and copper-jacketed asbestos) subjected to 2,000 psia and up to five thermal cycles from 150 to 475° F, the stainless-steel O-ring had measured leak rates ranging from 0.004 to 0.010 cm³/hr per inch of gasket diameter. The flat-copper leak rate varied between 0.001 and 0.014 cm³/hr, and the balance of the gaskets leaked visibly.

From these preliminary results it appeared desirable to subject the two most successful gaskets to a higher temperature and more extensive thermal cycling (150–575° F for 4 hr). In addition to the hollow stainless-steel O-ring and flat copper gaskets, tests were conducted on copper-jacketed stainless-steel mesh, flat and profiled zirconium, flat asbestos, flat Teflon and profiled stainless-steel gaskets.

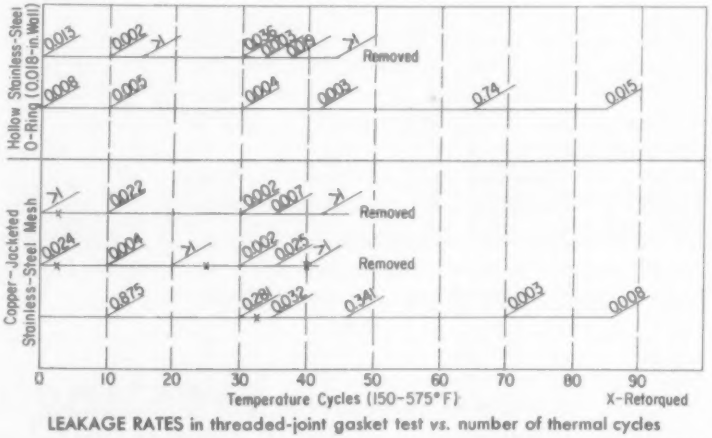
The testing was discontinued after completing 86 thermal cycles. All of the gaskets exceeded 1 cm³/hr at some point during the test except one stainless-steel O-ring and one copper-jacketed stainless-steel mesh (see figure). Two of the O-rings leaked visibly and then resealed without maintenance. The other two O-rings exhibited wide variation in leakage rates (0.003–0.75 cm³/hr per inch of gasket diameter) but did not have visible leaks. All of the copper-jacketed stainless-steel-mesh gaskets had visible leaks at some point and required retorquing the cap to reduce the leakage. Because of the O-ring's ability to reseal itself, it is felt to be superior to the mesh-filled gasket. The flat-copper gasket was not suited to the 575° F temperature—it leaked visibly even during the preliminary cycles.

These tests demonstrated two difficulties of the stainless-steel O-ring, however: (a) difficulty in withstanding repeated thermal cycling and (b) difficulty in achieving an initial seal. It is felt that the initial-seal problem could be improved by silver or Teflon plating of the O-ring to compensate for gasket- or joint-surface imperfections. The tendency to leak after 30 to 50 thermal cycles is a serious defect, in spite of its ability to reseal itself. This problem could be improved by using a closure design that does not subject the gasket surface to a rotating action—when the threaded joint is assembled, the gasket surface is scored by the action of the cap or body against the gasket.

Bolted-Flange Joint

The bolted-flange joint is not limited to any particular size and ranges up to the reactor vessel-to-head joint. Typical applications are in access openings to the pressurizer and steam generator or in large valves. The stainless-steel-wound-asbestos type gasket was found to be best for use in a bolted-flange joint. The measured leakage of this style gasket did not exceed 0.9 cm³/hr per inch of gasket diameter in five separate test series. This style gasket was unique in the bolted-flange test series in that thermal cycling did not have a progressively deteriorating effect.

One bolted-flange-joint test series by Armour Research Foundation used five styles of commercially available gaskets (~6 in. o.d.), including stainless-steel-wound asbestos, hollow stainless-steel O-ring, corrugated stainless steel, Monel sheet and thin compressed-asbestos sheet. These gaskets were tested in fixtures similar to a standard 2,500-psi, 4-in., tongue-and-groove joint. The gaskets were subjected to steady-state conditions of 2,000 psi



LEAKAGE RATES in threaded-joint gasket test *vs.* number of thermal cycles

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and 600° F for 240 hr and then to 100 thermal cycles of from 150 to 575° F in about 4 hr. With the exception of the thin compressed-asbestos sheet, which failed during the preliminary thermal cycling, all the gaskets completed the test.

The O-ring had hot leakage rates of ~0.04 cm³/hr per inch of gasket diameter for the first 50 thermal cycles. For the last 50 thermal cycles, excessive leakage (up to 3,780 cm³/hr) occurred sporadically following a 575–150° F thermal shock. During the next few cycles, the O-ring leaked visibly until a later thermal shock caused it to reseal. At the end of 100 thermal cycles the O-ring leaked 2 cm³/hr cold and 0.03 cm³/hr hot. When the device was disassembled there was no visible defect in the O-ring.

The corrugated stainless-steel and flat Monel-sheet gaskets behaved similarly. When the fluid temperatures were relatively constant, they exhibited leakages of 0.002–0.02 cm³/hr per inch of gasket diameter. Both of these gaskets leaked 30–50 cm³/hr for at least a 15-min period in switching from hot to cold for the last 20 cycles.

Two different manufacturer's stainless-steel-wound-asbestos gaskets were subjected to this entire test series. A 0.128-in.-thick gasket had the lowest, consistent, measured leakage: 0.002–0.04 cm³/hr per inch of gasket diameter. There was no apparent change in its leakage performance from the beginning to the end of the test. It was the only gasket having a visible leak during rapid temperature changes. This leak, however, was so small, of such short duration and so infrequent (11 out of 100 cycles) that a quantitative measurement was impossible. A 0.180-in.-thick gasket had an unsatisfactory leakage rate from the beginning.

Four of the 0.128-in.-thick stainless-steel-wound-asbestos gaskets were tested simultaneously for ten thermal cycles in four of the test flanges previously used. Leakage measurements were made hot and cold during the 1st, 5th and 10th thermal cycle. Two of these gaskets, with 31,000-psi gasket loadings, had no measurable leakage. The other two gaskets had a loading of 28,000 psi and their leakage measurements averaged 0.01 cm³/hr.

* * *

This article is based on pp. 30-38 of Reactor and plant engineering, WAPD-BT-9 (1958).

APDA Studies Fast-Breeder Improvements

With the Enrico Fermi Fast Breeder (EFFBR) in the final stages of erection, Atomic Power Development Associates (designer of EFFBR) is turning its attention to how it would design a second-generation fast breeder. This month (see p. 23) APDA hopes to complete a detailed design study for an improved large-scale [860-Mw(th)] plant (to be called the Plutonium Fast Breeder Reactor). The PFBR will take full advantage of APDA's hindsight on EFFBR and technological advances made since EFFBR started building. The resulting design improvements together with the larger plant-size [EFFBR is only 300 Mw(th)] should give PFBR a chance to show what fast reactors can do economically. Preliminary estimates put the total cost of the 300-Mw(e) PFBR at $83 million or $278/kw(e).

The PFBR design will include the following major improvements:

Core life. A new oxide fuel together with a larger core will allow a core life of two years with three months between unloading. The first EFFBR core has a life of only 14 weeks (1% burnup) and a 2 week unloading cycle.

Fuel-loading equipment. The less frequent loading plus greater experience with fuel-handling mechanisms will result in a much simpler fuel-loading scheme. The complicated offset handling mechanism, which at present is permanently installed in the reactor chamber, would be replaced by a simpler mechanism that would be brought in only during unloading.

Hydraulic hold-down. The smaller volume fraction of Na in the core will allow a hydraulic scheme for core hold-down instead of the present mechanical arrangement.

Heat exchanger. A new Na-to-Na heat-exchanger configuration (a result of the AEC's high temperature development program) will be more reliable and cheaper to build.

Radiation shield. Experience shows that the radiation shield (6–12 in. of stainless-steel) that protects the reactor vessel can be eliminated.

Shielding materials. A new high temperature neutron-shield material (called serpentine), the use of iron oxide as a cheap high temperature gamma shield, and a clearer understanding of neutron streaming problems have led to a radical change in shielding concept.

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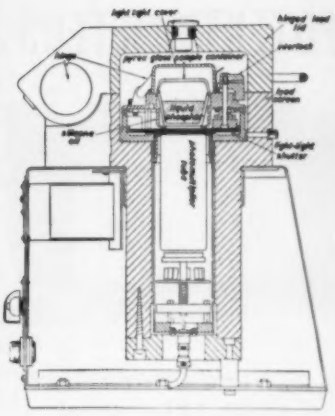

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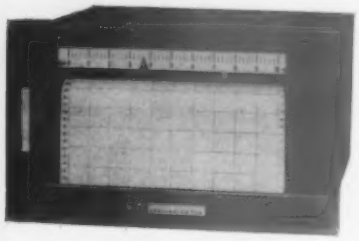

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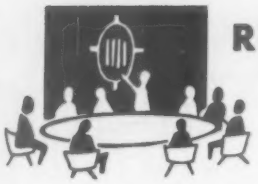


REACTOR ROUNDTABLE

A discussion place for new reactor ideas

Flowable Solids Reactor

By M. R. DUSBABEK

The Fluor Corporation, Ltd., Los Angeles, California

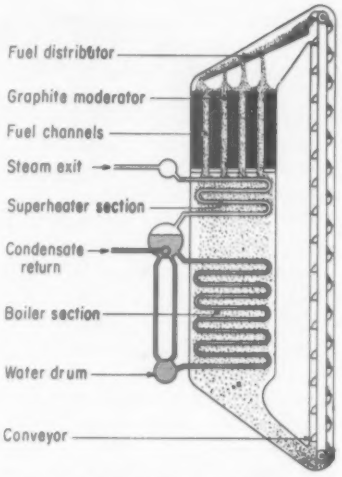
The Flowable Solids Reactor resulted from an attempt to design a reactor system that uses a cheap form of unclad fuel and at the same time avoids the problems that come with liquid fuels. The figure shows a schematic diagram of the proposed reactor system. The reactor fuel, crushed, fused UO_2, is in the form of a dry, granular, flowable powder with an average particle diameter of about 200 microns.

The material flows by gravity down through vertical fuel channels spaced in a graphite moderator. The bottom of each channel has an orifice that restricts the flow rate of the fuel to maintain a constant fuel density within the core. (The process is somewhat analogous to the flow of sand in an hour glass). As it passes down through the core the fuel is heated internally by fission and falls out of the orifice at a temperature of about 2,000° F.

The fuel channels are typically 3 in. in diameter and would have ceramic liners to prevent erosion of the graphite by the fuel material.

Primary System

After it leaves the reactor core, the hot fuel material cascades over steam-generator tubes located in a chamber directly beneath. The steam tubes are arranged horizontally on a triangular pitch with the superheater tubes located at the top (closest to the bottom of the reactor core), boiler tubes in the middle and the preheater section at the bottom. The fuel material is cooled, primarily by radiant heat transfer, to about 700° F as it passes down through the steam generator, is collected at the bottom, and recycled to the top of the reactor core by a mechanical conveyor. A distributor device spreads the fuel material across the top of the reactor core as it comes from the conveyor.



FLOWABLE SOLIDS REACTOR has UO_2 powder fuel that flows under gravity through graphite core, falls through heat-exchanger-tube array and is returned to core by mechanical conveyor

The reactor system contains helium at 1 atmos pressure. A small amount of helium continuously passes through an elutriator which removes the fuel fines and fission gases. The fines are reconstituted by either a sintering or fusing operation and returned to the reactor.

A structure of high temperature-fire brick and insulating brick encloses the reactor assembly and steam-generator tubes. This in turn is completely enclosed in a gas tight, water cooled steel container plus a gas-tight steel-lined biological shield. The latter serves as a containment shell for accidentally released fission products. Because the reactor operates at low pressure and no phase change occurs if the reactor vessel is ruptured, containment is not a major problem.

Although the fuel passing through the heat exchanger has some delayed

neutron activity, if the boiler water is kept very pure, the radioactivity in the steam will be negligible.

Because the temperature coefficient of reactivity is negative the reactor-load control can be automatic. Shim control can be had by adding small quantities of highly enriched uranium in the fuel-reconstitution operation. Simply stopping and/or diverting the conveyor discharge would be the most rapid way to produce an emergency scram; safety rods or plates would be more convenient for normal shutdown.

Studies of the best way to remove heat from the UO_2 powder after it has left the core ruled out the use of a fluidized bed because of the high cost and difficult maintenance involved in a large blower system and the large fuel inventory required. The blower would have to be absolutely leak tight, a serious problem. Dust would have to be completely removed from the recycled gas to prevent erosion of the blower blades. Calculations showed that the present much simpler scheme (direct-heat exchange from the particles to the steam tubes) was practical, although the steam-tube-surface area required is about 8-fold that required for a fluidized bed. However, the direct-exchange design uses less than 10% of the fuel inventory required for the fluidized-bed steam generator.

Fuel Cycle

The initial reactor fuel charge is 174 tons of UO_2 enriched to 0.98% in U^{235}. Since a large percentage of the fission products will be removed continuously with the gas-elutriation system, an average conversion ratio of 0.704 should be possible. Under these conditions, reactivity should allow a burnup of about 12,000 Mwd/ton. The fuel burnup is completely uniform because of the mixing in the steam generator after each pass through the core.

At an average power level of 320 Mw(th) and assuming full power operation for 290 days/yr, the initial fuel charge should be enough for about 20 years of operation. This assumes that the plutonium (occurring in an equilibrium concentration of about 0.5% by weight) will be retained (and converted, if necessary, to oxide) in the UO_2 fuel during the reconstitution process. The Pu is expected to have little effect on the physical performance of the fuel material.

If this proves not to be so, the Pu could just as easily be separated and

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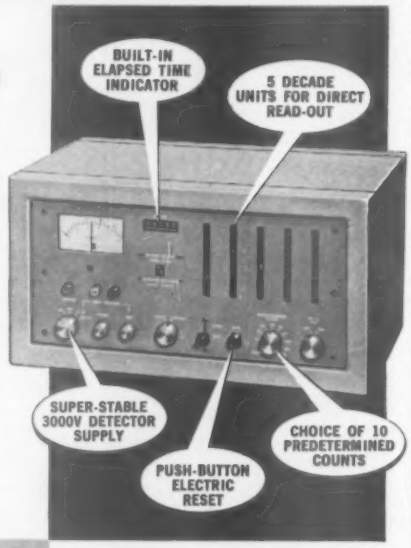
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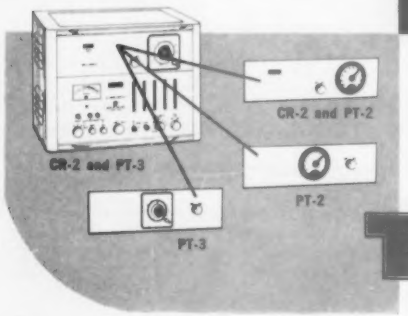

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sold during the reconstitution operation and U^{235} substituted.

Present designs call for a mechanical lift system to carry the UO_2 from the bottom of the steam generator to the top of the core. Although pneumatic lift systems of several types, including the so-called "mass-lift" system, are available, the problems introduced by these systems (i.e., large, leak-tight gas compressors, dust-removal equipment and fuel attrition caused by the high gas velocities) outweighed the advantage of smaller fuel inventory.

Mechanical conveyors (such as the Redler type) with the needed volume capacity (570 cfm) are available; however, a conveyor with the needed weight capacity (85 tons/min) has yet to be built. High-density materials such as UO_2 are not commonly transported in large quantities. But conveyor-equipment manufacturers feel that a conveyor of this kind with the necessary high degree of reliability, can be designed and built without a large development program. Such conveyors would be considerably more expensive than conventional ones.

In the reactor plant the conveyor-drive would be located so that normal maintenance is possible. Three conveyors would likely be installed, two of which would deliver the required 85 tons/min; the third would be a spare.

Design Uncertainties

Because capital costs will always be higher for nuclear plants than for conventional plants, a drastic reduction in nuclear fuel costs seems a necessary condition for competitive nuclear power. The homogeneous concept, in that it avoids all of the fuel-fabrication and some of the reprocessing charges that account for 80% of heterogenous-reactor fuel costs, appears to be a logical solution to this problem. However, previous reactors of this type (e.g., aqueous homogeneous, liquid metal, fused salt) have run into difficulties with corrosion, fuel stability, system pressure and fuel phase change.

The FSR, too, is faced with possible difficulties. Three major areas of uncertainty that must be investigated before the feasibility of the concept can be established are:

• Behavior of the fuel material in the reactor system (Will it flow as in-

tended? How fast will the fuel particles break up?)

- Radiant-heat-transfer steam-generator design
- Mechanical fuel-transport feasibility

Some evidence already exists on the first (and probably the most critical) of these problems.* Experiments show that (a) crushed, arc-fused UO_2 appears to be the most suitable fuel material, (b) the UO_2 attrition rate from thermal and physical shock is about 7.5% of the total inventory per month and (c) arc-fused UO_2 will flow, with no tendency to stick or agglomerate, at temperatures above 2,000° F. Data for -65 $+100$ mesh, arc-fused UO_2 suggest that the flow rate is fairly independent of fines content (to 30% fines) and temperature up to the temperature at which flow ceases.

The economics of the fuel cycle are quite sensitive to the rate of fuel-particle-size degradation. Fuel-particle breakup will be caused by three mechanisms:

- Thermal shock
- Physical shock
- Radiation damage

The first two mechanisms have been experimentally measured to a limited extent. The data indicate that these two mechanisms will cause about 7.5% fines per month. Because the average exposure prior to reconstitution will be relatively low ($\sim$ 500 Mwd/ton), the breakup due to radiation damage should be almost negligible, based on reported radiation-damage studies.

Another question that comes up is what would happen to the reactor core if one of the fuel channels, for one reason or another, becomes plugged. The temperature of the graphite surrounding the plugged channel would begin to increase at a rate of about 1.5° F/sec until the temperature was high enough to transfer the heat generated in the plugged channel to the fuel flowing in the adjacent channels. This equilibrium condition should be reached in about ten minutes. The plugged fuel channel, of course, will become a permanent fuel element and will ultimately reduce the thermal capacity of the reactor by about 0.4%.

Also if a channel were to become plugged (due perhaps to an obstruction in the orifice), the resulting fused plug will have a higher density causing a local increase in reactivity. The core,

* R. C. Oliver et al, System evaluation of the Flowable Solids Reactor, FLR-1 (January 1958).

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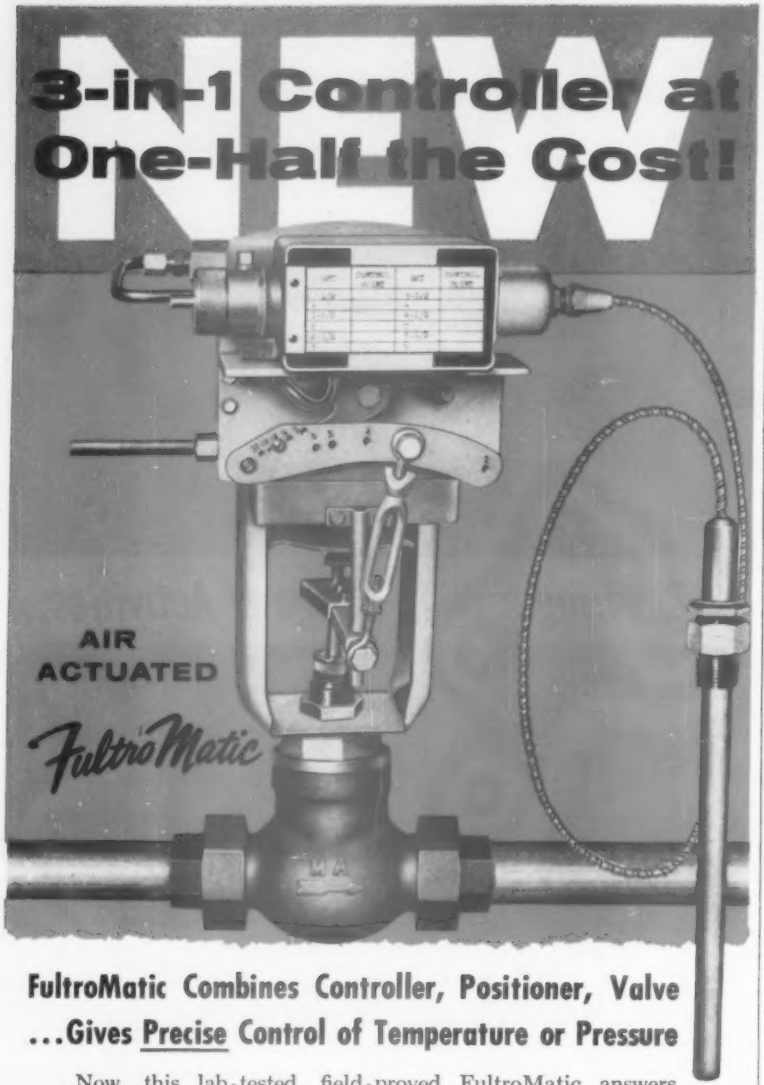

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This article starts on page 128

however, is large compared to the slowing-down length so that the overall reactivity should not be seriously affected.

Thermal expansion of the fuel material itself is not likely to cause plugging because of the thermal inertia of the system and the rapid flow of the fuel material. Also the "flow" density of a solid is slightly less than the "poured" density.

Economics

The total estimated installed cost for a 100 Mw(e) Flowable Solids Reactor, including contingency and fee, is $22,260,000. For an 80% load factor and 15% fixed charges, the energy cost attributable to capital charges is 4.77 mills/kwh.

The fuel cost is computed under the following assumptions:

- The initial fuel charge is leased from the AEC at 4% per year.
- At the end of twenty years, the fuel is reprocessed at $15/kg.
- Recovered plutonium is valued at $12/gm.
- Initial fuel preparation charges are $2/lb or $700,000 total with sinking fund charges of 7.4% per year. Fuel reconstitution charges are covered under operation and maintenance.

The total energy cost may be summarized:

	mills/kwh
Capital	4.77
Fuel inventory	0.72
Fuel burn-up	0.37
Amortization of initial fuel preparation charges	0.07
Operation and maintenance	1.00
Total	6.93

* * *

The experimental work referenced here was performed under Contract AT(04-3)-131 with the AEC.

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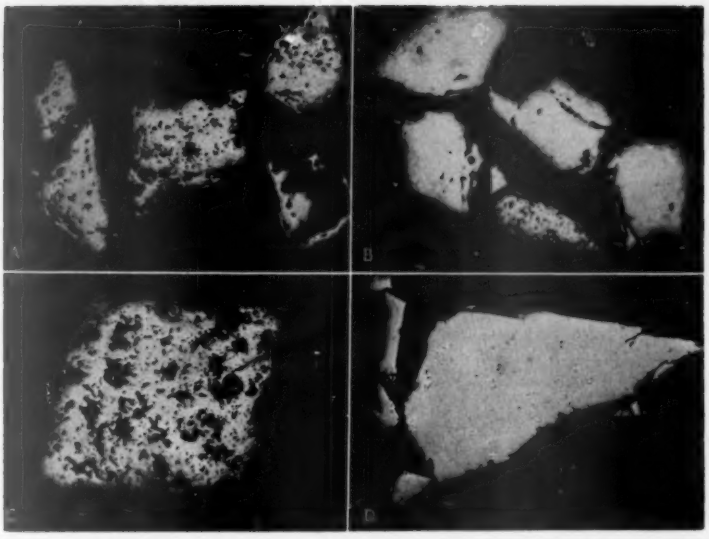

FIG. 1. UO_2 particles formed by reduction of (A) calcined ammonium nitrate, (B) calcined peroxide cake, (C) UO_3-monohydrate. Particles show characteristic porous structure obtained with reduction processes. D shows very dense particles produced by fusion. (Magnifications are ~250×)

An Evaluation of UO_2 Dispersions

By E. N. MAZZA and W. R. WEINBERGER
Sylvania-Corning Nuclear Corp., Bayside, New York

The increased use of uranium oxides in dispersion-type fuel elements has resulted from the increased demands for fuel materials capable of high-temperature operation and high burnup.*

Uranium-metal and -alloy fuel elements are limited to operating temperatures below the phase-transformation temperature of ~660° C. Other limiting factors are the dimensional instability resulting from radiation damage and thermal cycling, low corrosion resistance to water and the limitations placed upon the type of clad materials (e.g., stainless steel and uranium react to form a low-melting eutectic phase).

The most common dispersion fuel is uranium dioxide (UO_2) in an aluminum or stainless-steel matrix. A stainless-steel dispersion is being used in the Army Package Power Reactor and an aluminum dispersion in the Geneva (1955) swimming-pool reactor.

UO_2 Preparation

Uranium dioxide suitable for fuels can be produced by various methods: reduction of calcined uranyl nitrate, calcined ammonium diuranate, calcined peroxide cake and UO_3-monohydrate (forming what is commonly known as Geneva Oxide); and steam oxidation of uranium metal or hydride.

Each method of UO_2 preparation results in a characteristic particle shape (Fig. 1). Geneva oxide reacts to a lesser extent than other oxides in an aluminum matrix.

Fusion of UO_2 at 2,600°–2,800° C yields very dense particles (Fig. 1). This technique, however, is not as yet feasible as a production method because of UO_2 losses caused by its high vapor pressure.

In general, UO_2 particles used in dispersions should have high density and high strength. In addition, particle

* Irradiation data have been obtained at Oak Ridge and Battelle for roll-clad stainless-steel-dispersion fuel plates. The ORNL plates (type 304 matrix, type 304 L clad, 18 wt % UO_2, 5-20-5-mil clad-core-clad thickness) were taken to 2.1% of total atoms burnup at 190° F surface temperature and 6.0×10^{13} $n_{th}/cm^2/sec$ flux without failures. No failures were experienced with BMI plates (elemental-powder matrix—73% Fe, 18% Cr, 9% Ni—type 347 clad, 30 wt % UO_2, 4-12-4-mil plates) taken to 2.6 atom % burnup at 650° F and 7.0×10^{13} flux. (J. E. Cunningham, R. J. Beaver, paper 1925, 2nd United Nations Conference on the Peaceful Uses of Atomic Energy.)

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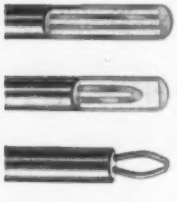

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This article starts on page 137

TABLE 1—Experimental Powder Mixes

Mix No.	*347-stainless mesh size*	*UO_2 mesh size*
1	−100 + 325	−140 + 325
2	−100 + 325	− 325
3	− 325	−140 + 325
4	− 325	− 325

size is an important factor in radiation damage.

A granulation (coarsening or agglomerating) process is the best means of meeting these requirements. This process is also useful in production runs, since oxide particles can be recycled indefinitely, thus avoiding scrap losses due to undersize material.

Fuel-Element Fabrication

While dispersion-type fuel elements can be fabricated as tubes, rods, wires and other more complex shapes, plate-type elements are the most common current form.

The steps involved in making plate-shaped elements are compacting UO_2-metal powder mixtures into rectangular cores, assembling into conventional picture frames and fabricating the assembled unit by hot-rolling to densify the core and bond the cover plates to the core and picture frame. Finally, cold rolling is employed to meet dimensional specifications and improve surface condition.

Studies of core materials for plate-type elements have been conducted to determine the effects of such variables as UO_2 particle size, matrix particle size, compacting pressures and sintering. Early work indicated that radiographic evaluation of as-compacted cores, prior to element fabrication, is an excellent technique for determining homogeneity of a finished plate.

Particle size. Combinations of various sizes of UO_2 and stainless-steel particles yield compacts with UO_2 distributions ranging from poor to good. To resolve this phenomenon, four mixtures of various particle sizes were prepared (Table 1) containing 26 wt% UO_2.

Two compacts from each of the four mixes were pressed at 50 tons/in.^{2} All of the compacts were then radiographed. Typical radiographs are shown in Fig. 2. Compacts produced from mixes Nos. 1 and 2 appear to be badly segregated, while mixes Nos. 3 and 4 exhibit excellent distribution. Similar results were obtained with mixtures containing 18, 23 and 30 wt% UO_2 in stainless steel. An investigation of aluminum powder and up to 70 wt% UO_2 yielded identical results. Consequently, for the best distribution, it is essential to employ a metallic matrix material of −325 mesh particle size.

Evaluation of these particle sizes was continued throughout the fabrication processes to a finished plate. No appreciable effect due to any subsequent fabrication process was noted. It might be mentioned, however, that as UO_2 particle size increased, a tendency toward particle fragmentation and stringering increased during cold-rolling. This can be noted in Fig. 3.

Compacting pressure. Variations in compacting pressures on the unsintered core were also investigated. The core material consisted of blended, as-received type 304 stainless-steel powder and 18 wt% 80-mesh, steam-oxidized UO_2. Sample cores were compacted at 33, 50 and 65 tons/in^2 and then evaluated for density and for modulus of rupture. The results are shown in Table 2.

The samples pressed at 33 tons/in^2 were powdery on the edges and tended to crumble on being handled. Compacts pressed at 50 tons/in^2 could be handled in the as-pressed condition without damage. As evidenced in Table 2, samples compacted at 65 tons/in^2 had extremely high strength properties. Based on these results, it was

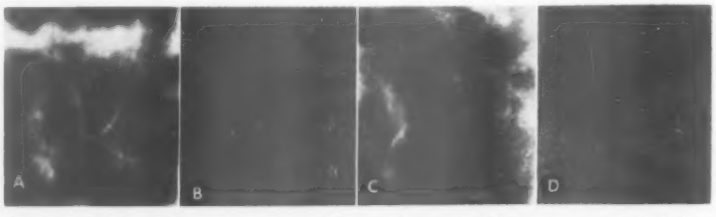

FIG. 2. Radiographs of compacted UO_2-stainless mixes (mixes are those listed in Table 1—A is mix 2; B is mix 4; C is mix 1; D is mix 3). A and C show segregation; B and D show excellent distribution. Thus, −325 mesh matrix powder is recommended

TABLE 2—Compacting-Pressure Effect

Pressure (tons/in²)	*Density (gm/cm³)*	*Modulus of rupture (lb/in²)*
33	6.15	1,250
50	6.80	1,825
65	6.90	3,050

felt that 50 tons/in² provides adequate strength. A compacting pressure of 65 tons/in² was considered impractical in view of the shortened die-life expectancy.

Since aluminum powders have excellent compacting characteristics and resultant high green strengths, an investigation of the effects of compacting pressures on an aluminum matrix was not necessary. Compacting pressures of 20–30 tons/in² were used to yield compacts having densities of 85–95% of theoretical, dependent upon the quantity of UO_2.

Sintering. A study was made to determine if sintering the cores to high density improved the properties of fabricability of stainless-steel fuel plates. Sintering of aluminum fuel plates was not deemed feasible.

Six compacts of stainless steel and 18 wt% UO_2 were compacted at 50 tons/in.² These compacts had a green density of 80–85% of theoretical. Three of them were sintered at 1,350° C for 16 hr in a dry-hydrogen atmosphere and three were left in the as-compacted state. The as-sintered densities were all 95% of theoretical. All six cores were inserted into picture frames and hot- and cold-rolled to finished size.

No difference between the fabrication characteristics of the as-compacted or as-sintered cores was noted. Also, metallographic examination revealed no structural difference between the fabricated cores. It was, therefore, concluded that sintering is not necessary.

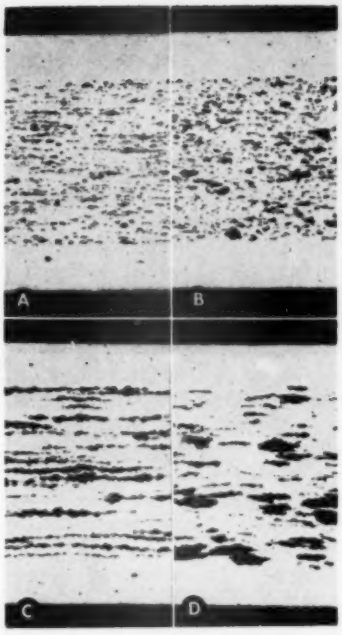

FIG. 3. Microsections (~50× magnification) of cold-rolled, 0.030-in.-thick UO_2-stainless plate. A (longitudinal section) and B (transverse section) are of plate having as-pressed core of 25 wt% −325 mesh granulated UO_2 in −325 mesh type 347 stainless matrix. C (longitudinal section) and D (transverse section) are of plate having as-pressed core of 25 wt% −140 + 325 mesh granulated UO_2 in −325 mesh type 347 stainless

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Nitrogen—Feasible Cover Gas

Inert rare gases are used to blanket liquid metals, e.g., sodium, because of unfamiliarity with less expensive gases. The principal concern in the case of nitrogen is its possible dissolution in sodium and resultant attack on containment materials. C. H. Lemke and W. C. Sharples (E. I. du Pont de Nemours & Co., Niagara Falls) report that nitrogen is insoluble at 100° C and 1-atm. pressure.

The analytical procedure had a sensitivity of 5 ppm nitrogen in liquid sodium. It consisted of bubbling argon through sodium at 100°–150° C for 3 hr and passing the argon over titanium sponge at 750°–800° C to absorb any nitrogen removed from the sodium.

The possibility of nitrides being in commercial sodium was also checked. A modified Kjeldahl procedure, having a sensitivity of 2–3 ppm, indicated no nitrides exceeding this limit.

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Irradiating Sewage Might Improve Bacterial Nutrients

In two recent Applied Radiation columns we have discussed problems and prospects of sewage irradiation. In the first (NU, July '58, p. 106) we pointed out that the net conclusion to be drawn from many studies appears to be that irradiation holds out many prospects but so far it is too expensive. In the second (NU, Oct. '58, p. 116) a letter from Carlos Bell of Northwestern University suggested (1) using heat and radiation to dry and sterilize sewage sludge and (2) irradiating conventionally treated sewage in an attempt to improve the microorganisms by genetic mutation.

The two previous items have inspired the following further comment from Eric B. Fowler, Chief Chemist-Bacteriologist, H-7, at Los Alamos. His experiments discourage the feeling that one can expect beneficial mutations. But he suggests that radiation might be used to improve the food supply of microorganisms already present and thereby improve their action. His letter follows verbatim:

We have read Carlos Bell's letter in the October NUCLEONICS with interest. Thoughts on beneficial uses of radioactive waste products are always welcome; the article should surely stimulate interest along these lines. The following comments are meant as additional thoughts that may be of some value rather than as adverse criticism of Bell's stimulating article.

It is our feeling that the place of radiation in sewage treatment is more probably to alter the available food supply rather than to alter the microorganic population.

Organisms Need Food

Investigations that we have conducted under disposal-plant conditions indicate that the controlling factor in disposal is not lack of an active population but lack of a readily available food supply for organisms that already exist. Chromatographic technique demonstrates the absence of an expected high concentration of readily available nutrients in normal sewage. Only one amino acid, identified as lycine, and an unknown carbohydrate are found to be consistently present.

Apparently the microorganic population in sewage is such that nutrients are metabolized as rapidly as they become available; this process appears to be slow, and it limits the population. A population shift is noted on introduction of more nearly anaerobic or aerobic conditions. However, chromatographic techniques do not demonstrate a change in amino acid or carbohydrate content of the sewage, again indicating that the poulation is fully metabolizing the readily available food supply. In *in vitro* laboratory experiments addition of crude molasses enhances disposal rates as shown by an increased population and a more rapid reduction in biochemical oxygen demand.

Genetic Mutation

Bell suggests a "highly mutating gamma source" to produce organisms more efficient in the disposal of sewage. Here at Los Alamos we have investigated, in a preliminary way, the effects of gamma and neutron irradiation from the "water boiler" reactor on activated sludge. Several energy levels and exposure times have been studied. In general, a simplification of the bacterial population accompanies increasing dose rates or increasing exposure times. There is no evidence of a mutant replacing the normal population. However, it should be pointed out that isolation and identification of mutants as such were not a part of the investigation.

One observation worthy of note is concerned with the disintegration of a normal sludge when certain exposure rates are used. Such sludge, returned aseptically to the activation column, gradually disperses and will not agglomerate even though a viable population is present.

Biological disposal of sewage is an enzyme-dependent reaction. Radiation does not produce new enzymes; rather it tends to destroy some enzymes that are already present in the cell. The possibility of producing a "super organism" with the required enhanced enzymatic make-up through irradiation of a population seems questionable.

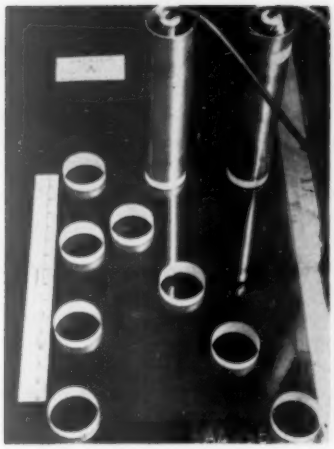
The literature is replete with examples of mutations obtained by irradiation of a population. Tatum and Beadle have shown the possibility of "producing" an organism with certain enzymatic characteristics.* However, these mutants are not "super organisms." Rather they lack some ability possessed by the parent. Instances of production of "super organisms" are noticeably lacking in the literature. One does not expect them since damage to any link in an enzymatic chain is expected to produce an organism less able to obtain food from its environment than its progenitor. The possibility of a "super organism" is not ruled out; it merely becomes very remote indeed.

Providing Food

In view of the above results one can profitably speculate on the use of high-energy gamma or neutron radiation on sewage to break bonds in complex protein or carbohydrate molecules prior to sludge activation, thus releasing food for other bacterial populations in normal untreated sewage. This food would be more readily available to metabolism by the enzyme complexes of the latter bacterial population. Results obtained by irradiation of sewage sludge at the water-boiler reactor may be informative in this respect. A chromatographic analysis of sewage sludge, irradiated but not sterilized, demonstrates an increase in ninhydrin-positive components; these would be peptides or amino acids. A Warburg gas-exchange analysis of the treated sludge shows increased oxygen uptake and carbon dioxide evolution. Plate counts on the treated sludge often show no growth, indicating that the organisms can metabolize but have lost their ability to reproduce. Increased concentration of readily available nutrients could result in increased oxygen uptake.

---

* G. W. Beadle, *Am. Scientist* **34**, 31 (1946); E. F. Gale in "Bacterial Physiology," p. 458, C. H. Werkman, P. W. Wilson, eds. (Academic Press, New York, 1951); G. W. Beadle, E. L. Tatum, *Proc. Natl. Acad. Sci. U. S.* **27**, 499 (1941).



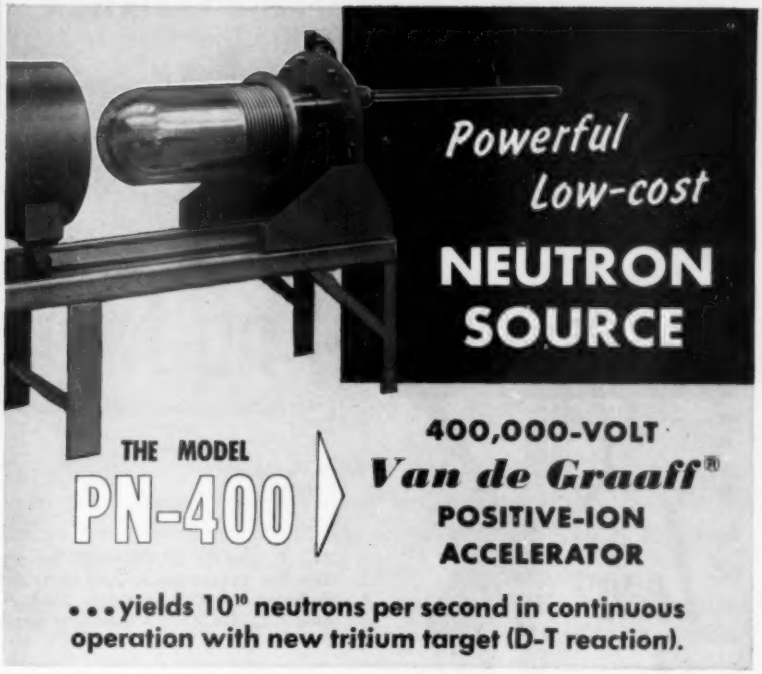
Kr^{85} Traces Oxygen in Metal Honeycomb

Metal honeycombs brazed to skin surfaces make light, strong panels for aircraft construction. But the brazing isn't easy. It must take place in an atmosphere in which oxygen is reduced to 10–100 ppm. Oxygen removal is accomplished by evacuating the brazing retort, filling with argon, evacuating again and so on. About 8 purge cycles are normally used. On evacuation, gas in the cells must flow out through 5-mil holes in cell walls. How can you tell whether oxygen has been effectively removed?

Donald Wright and Kennedy Wilson use Kr^{85} for this determination at Boeing Airplane Co. in Seattle. They use a simulated retort made of reinforced Fiberglas, a honeycomb covered with Mylar and a scintillation counter to detect 0.67-Mev betas from the krypton. The figure shows their setup. On top is a 1-in. piece of Lucite with holes for the scintillation counters.

The procedure is to admit 10 mc of Kr^{85} to the retort and allow it to mix thoroughly with the gases there. The observed counting rate is taken to represent normal oxygen concentration, 210,000 ppm. Counting after successive purges indicates that oxygen is likely to be retained in the center of the panel and removed only slowly.

Kr^{85} appears to be the best of three usable gaseous tracers. Others considered were tritium and Xe^{133}. Advantages of Kr^{85} are its 9.4-yr half-life, its 0.67-Mev beta and its chemical inertness that makes it biologically safe (NU, March '57, p. 66). Its molecular weight of 85 is not very close to the 32 of oxygen, but it is near enough for these purposes. An outstanding disadvantage is that krypton



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This article starts on page 141

cannot represent the adsorption that may occur on cell walls. Wright and Wilson are exploring this by other means.

Kr^{85} is expected to remain useful in further experiments that will use the actual metal retorts used in brazing. Betas cannot escape to counters on the outside, but Kr^{85} has a 0.54-Mev photon in 0.65% of its disintegrations. Greater concentrations will enable recognition of this photon above the existing background.

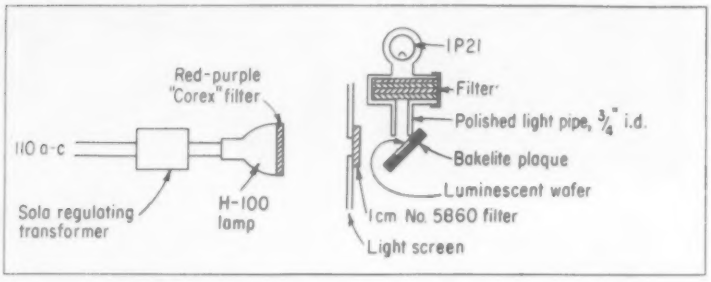

FIG. 1. SIMPLE FLUORIMETER for reading dosimeters before and after exposure uses filter to separate exciting ultraviolet and fluorescent light. Phototube filters, top to bottom, are: Corning Nos. 5113, 4 mm (blue); 3387, 6 mm; 3389, 3 mm; Baird Nos. 7-3233-4, 4380-A bandpass (interference)

High-Level Dosimetry by Luminescence Degradation

By FRANK H. ATTIX
U. S. Naval Research Laboratory, Washington, D. C.

A dosimeter accurate to ~10% for dose ranges of 5×10^5–5×10^9 rads has been developed in this laboratory. It consists of two penny-sized wafers of anthracene and *p*-quaterphenyl. One reads the wafers before and after irradiation with a fluorimeter that excites with 3,650-A ultraviolet and measures the resulting fluorescence at 4,420 A with a photomultiplier. Dose-rate effects are negligible, at least in the range 5×10^5–3×10^8 rads/hr.

The dosimeters are small, relatively sturdy and easy to manufacture and manipulate. The fluorimeter is a simple system that uses filters to isolate exciting ultraviolet light and emitted fluorescent light. Commercial fluorimeters may be adaptable for this purpose.

Previous Work

Several earlier papers have reported the decrease in efficiency of several organic luminophors for both scintillation and ultraviolet photoluminescence on exposure to ionizing radiation (*1–4*). Luminescence degradation has also been studied in other types of materials such as alkali halide phosphors (*5, 6*), quinine acid solutions (*7*) and xylene-PPO solutions (*8*).

Anthracene and naphthalene have been found useful for gamma and electron doses at least over the range 3×10^5–2×10^8 rep, and using them in a self-supporting plaque for convenience and accuracy has been suggested before (*4*).

Dosimeter Wafers

To cover a wide range of doses with adequate sensitivity, we use two organic materials of differing degradation characteristics: anthracene [C_6H_4:(CH_2):C_6H_4] and *p*-quaterphenyl ($C_6H_5C_6H_4C_6H_4C_6H_5$). Powders of these materials are pressed into wafers 1/16 in. thick and 3/4 in. in diameter, weighing 0.5 gm. The anthracene (Reilly Tar & Chemical Corp., scintillation grade) is molded at 20,000 psi pressure and a temperature of 150° C, and the *p*-quaterphenyl (Eastman Kodak) forms sound wafers under pressure alone without heating. Thinner wafers have been easily fabricated.

The predose luminescence of the wafers is reproducible within a few percent among different wafers even for

our relatively simple techniques. Finely divided raw material (e.g., Eastman *p*-quaterphenyl) gave the best reproducibility in this respect—about 1–2%.

Because of very strong absorption of the exciting ultraviolet in the luminescent material, only luminescence in a thin surface layer is observed. Some 90% of the signal comes from the first 4 microns of anthracene (*9*). Thus the quantity measured by these dosimeters is the absorbed dose in the wafer surface. One consequence is that each wafer yields two measurements of luminescence, one for each side of the wafer. In a gamma-ray measurement where electronic equilibrium conditions are satisfied (*10*), the two measurements should agree, and can be averaged to give improved accuracy.

Furthermore, surface luminescence degradation is strongly influenced by secondary ionizing particles coming from adjacent material outside the wafer as well as from within. This should lead to great versatility in manipulating the response of the device to neutron and mixed fields, as well as gamma rays. These possibilities are being investigated further in this laboratory.

However, for simplest application to gamma-ray measurement, the wafers should be enclosed during irradiation in a capsule of a low-atomic-number material such as polystyrene or graphite. The capsule wall thickness should be at least equal to the range of secondary electrons produced by the gamma rays. In general the wafer surfaces should be protected from contamination or abrasion during use to avoid spurious changes in measured luminescence.

Fluorimeter

Figure 1 is a schematic diagram of a breadboard fluorimeter designed for measuring the ultraviolet-excited photoluminescence. The dosimeter goes into circular recess in a dead-black Bakelite plaque with its surface exposed to 3,650-A ultraviolet light from an H-100 mercury lamp. Lamp-to-plaque distance is adjusted so that an undosed dosimeter gives a photomultiplier current about 10^4 times dark current—several microamperes. At this level, photomultiplier fatigue in the 1P21 is negligible and no ultraviolet-induced luminescence degradation is observed even after an all-day exposure in the fluorimeter (*4*). The filter combination in Fig. 1 reduces the signal caused

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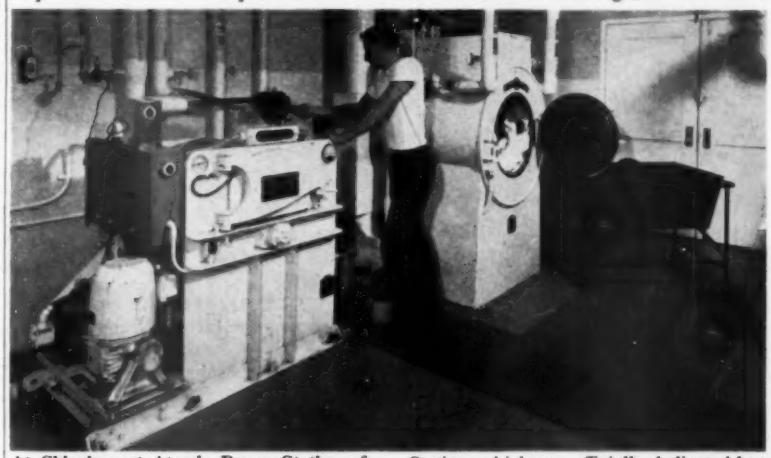

At Shippingport Atomic Power Station of Duquesne Light Co., in Shippingport, Pa., clothing of workers in the Reactor Plant is decontaminated and laundered with the two Cascadex Washer-Extractors and two Zone-Air Drying Tumblers, one of each pictured above. A joint project of the U. S. Atomic Energy Commission and Duquesne Light Co., the Shippingport Power Station, which was officially dedicated last May, is the world's first commercial atomic energy plant. Upon completion of their work, employees remove their clothing, shower, and monitor themselves for contamination before dressing to go home. The contaminated clothing is collected and laundered, then put in storage cabinets for reissuing.

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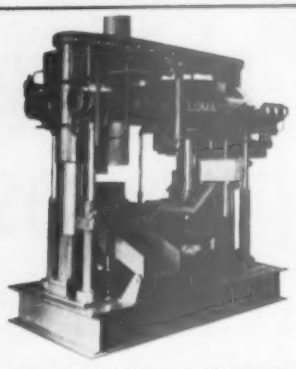
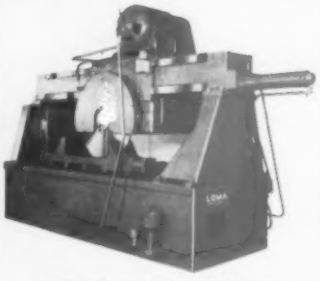
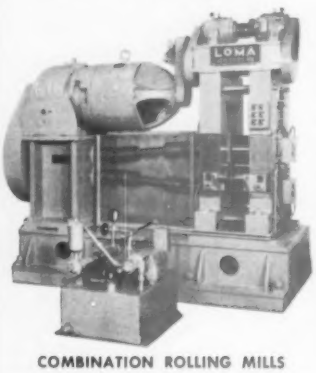


CONTINUOUS CASTING MACHINES



CIRCULAR SAWING MACHINES



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This article starts on page 142

by scattered ultraviolet to a very low level.

The photomultiplier is operated at −700 volts, supplied by batteries for stability, and its current output is measured on a General Radio Type 1230-A electrometer.

The dashed curves of Fig. 2 show the emission spectrum of anthracene and quaterphenyl wafers, as seen by a grating radiometer with 3,650-A excitation and a 1P22 photomultiplier filtered by a Corning 3060 filter. These curves have not been corrected for the wavelength dependence of the radiometer response, which tends to be too low below about 4,300 A. The solid curves were obtained by placing the exit filters from the fluorimeter in the radiometer and observing the resulting spectrum. Evidently the fluorimeter looks at a narrow band centered at 4,420 A and greatly attenuated by the filters. Quaterphenyl gives roughly half the undosed signal on the fluorimeter that

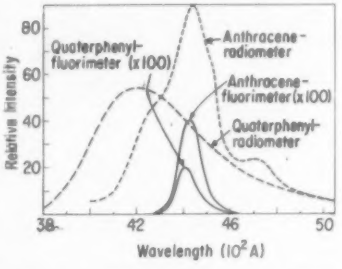

FIG. 2. COMPARISON of emission spectra and fluorimeter readings show that instrument reads narrow band centered at 4,420 A

anthracene does. Thus the two dosimeters can be measured easily on the same fluorimeter without any modification in the filter system. It is important for comparing results with different fluorimeters that their filter systems be identical. Then the same spectral band of luminescence is observed in each.

Degradation and Dose

Wafers were exposed to two types of ionizing radiations, Co^{60} gamma rays delivering $\sim 5 \times 10^5$ rads/hr to the dosimeter and the electron beam from a 2-Mev, 20-μa Van de Graaff generator at about 10^3 times the Co^{60} dose rate. The two sources were calibrated with the Fricke ferrous sulfate dosimeter.

Figure 3 shows degradation as a function of absorbed dose for both anthracene and quaterphenyl wafers. In each case the dashed curve was obtained from measurements made within

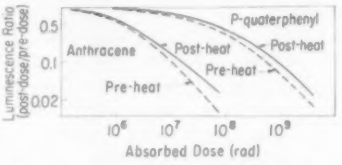

FIG. 3. LUMINESCENCE RATIO becomes stable after heat treatment. Without treatment, dose effect diminishes in time

~1 hr of irradiation. Contrary to previously reported results (*1–4*), luminescence in both anthracene and quaterphenyl recovered slowly with time after exposure. Amount of recovery is always small compared to initial degradation, but usually significantly large from the point of view of accurate dosimetry. The effect is somewhat greater for Van de Graaff runs than for those of Co^{60} gamma rays. Figure 4 is the recovery of anthracene wafers given 4×10^7 rads in the Van de Graaff electron beam. A post-irradiation heat treatment of 1 hr at 100° C was adequate to make readings very stable with time thereafter.

Co^{60} data were stable within 1–2% over a month's time, and electron-beam data were constant within 4–5% over that period. The solid curves in Fig. 3 were obtained after such a heat treatment. This heating generally has only a slight effect on luminescence of undosed wafers.

Under some conditions—for example, exposures in conveyor-belt-irradiation monitoring—the postdose heat treatment could well be dispensed with. In that case long-term stability of the luminescence is of secondary importance, and the similarity of successive exposures would enable establishment of a simple relationship between promptly measured degradation and that measured after heat treatment.

The cause of postdose recovery is uncertain, but an auxiliary experiment with ultrapure anthracene contained in an argon atmosphere has shown that the effect very likely is not caused by oxygen or initial impurities. Volatile degradation products have also been eliminated as a possible cause. Primary degradation can probably be ascribed to formation of a quenching molecule in the material. Under ultraviolet irradiation this quencher readily captures energy and dissipates it as heat before a normal molecule can emit the energy as light. Recovery may be

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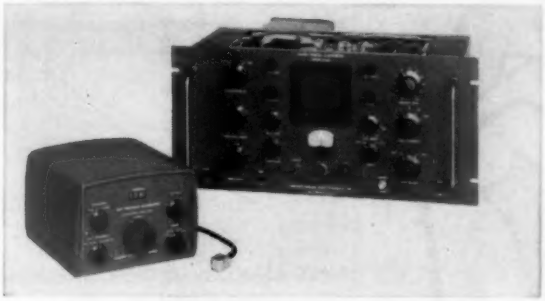

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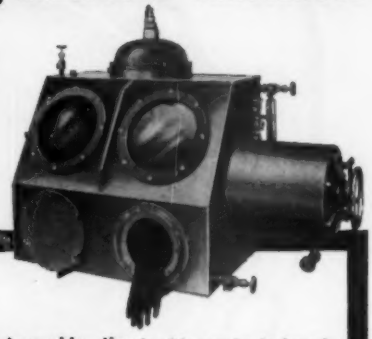

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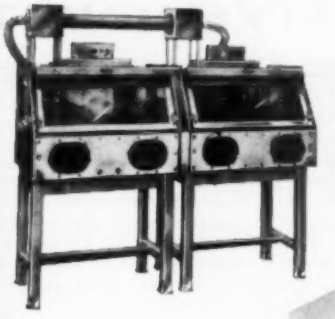

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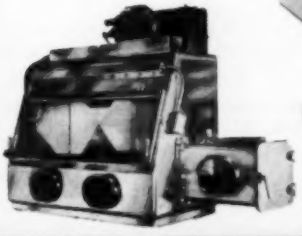

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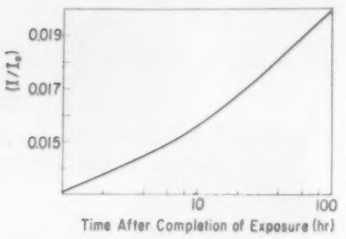

FIG. 4. RECOVERY OF DOSIMETERS in the absence of heat treatment. Ordinate is ratio of fluorimeter current to immediate predose value

caused by gradual chemical interaction between this quencher and some other radiation product. Alternatively, part of the quenching may be due to thermally unstable molecular species or to thermally unstable centers of the trapped-electron or trapped-hole type generally found in inorganic materials. In either case elevation of the temperature would tend to speed up the process. One hour at 100° C is adequate to reach a stable end point. Tripling the heating time produces no further change.

Others have considered the problem of physical interpretation of the primary degradation process (*1, 8, 11, 12*), which need not be discussed further here. However, it is worth mentioning that on a plot of $(I_0/I) - 1$ as a function of dose the anthracene pre-heat data fall on a straight line, while the post-heat data curve downward slightly with increasing dose. Quaterphenyl gives straight lines for both pre- and post-heat data up to 4×10^8 rad. Then the slopes break abruptly and give two steeper straight lines out to 5×10^9 rad at least. This suggests the possibility that a second quenching process becomes important in quaterphenyl at very high doses.

Rate and Energy Effects

Calibration of the Co^{60} source and Van de Graaff electron beam by chemical dosimetry allows a test of dose-rate dependence over a wide range of dose rates. The ferrous sulfate dosimeter is dose-rate independent at least over the range of interest here (*13*). The published depth dose distribution curve in water (*14*) for a 2-Mev electron beam was used to deduce surface dose for a dish of ferrous sulfate solution from the measured average volume dose.

Wafers of anthracene and quaterphenyl were given 5×10^7 rads with both Co^{60} gamma rays and the electron beam, and their luminescence degrada-

tion compared after the usual heat treatment. Absorbed dose indicated by the anthracene was 8% lower for the electron beam than for gamma rays, and the corresponding figure for quaterphenyl was 11% lower. This agreement between wafers and ferrous sulfate is regarded as satisfactory since it is probably within the accuracy of the ferrous sulfate calibration of the electron beam. It is particularly gratifying that anthracene and quaterphenyl track each other almost perfectly in going from Co^{60} to the electron beam. One probably obtains a better calibration of the electron-beam surface dose rate through the organic degradation dosimeters than by ferrous sulfate. In any case the dose-rate dependence of the degradation dosimeters is negligibly small, at least in the range 5×10^5–3×10^8 rad/hr. It is likely that this range extends considerably further in both directions, limited by possible heating effects at very high dose rates.

Effect of photon energy. With electron equilibrium, absorbed doses in two materials suffering the same exposure are in the ratio of their energy-absorption coefficients (*10*). A calculation of this ratio for anthracene and quaterphenyl relative to carbon shows that it does not differ from unity by more than ±6% over a range of photon energies of 10 kev to 10 Mev. Thus these dosimeters are well suited to dosimetry measurements in low-atomic-number materials in general and carbonaceous ones in particular.

Interpretation

This system is not absolute and must therefore be calibrated against a reference—for example, ferrous sulfate solution. This is most directly done in a gamma-ray field under equilibrium conditions. Absorbed dose in the wafer is determined from the absorption coefficients. For Co^{60} gamma rays absorption coefficients in square centimeters per gram are as follows: anthracene and *p*-quaterphenyl, 0.0282; water, 0.0297; graphite, 0.0267; polystyrene, 0.0287; air, 0.0267. Ferrous sulfate dosimetric solution has a value close to that of water.

If the exposure dose rate R (roentgens/hr) is known at a point in the gamma-ray field, the absorbed dose rate (rads/hr) in a degradation dosimeter at a point under electron equilibrium is $D_x = 0.877 R \mu_x/\mu_{air} = 0.93R$.

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study in this laboratory. In particular the effects of temperature and application to electron beams, mixed neutron and gamma fields, and beryllium-window X-rays are being considered further. The present report is intended only as an introduction, and will be extended as further work is completed.

* * *

The author wishes to express his appreciation to J. H. Schulman for vital contributions throughout the work, R. D. Kirk for providing ultrapure anthracene and valuable assistance in one phase of the project, A. E. Nash for his advice and the use of his equipment in carrying out the ferrous sulfate dosimetry, and J. G. Allard, C. F. Sharn and the other members of the NRL Dielectrics Branch who have generously contributed their time. The research was supported in part by the United States Air Force under Contract No. (33-616)-58-21 monitored by Materials Laboratory, Directorate of Research, Wright Air Development Center.

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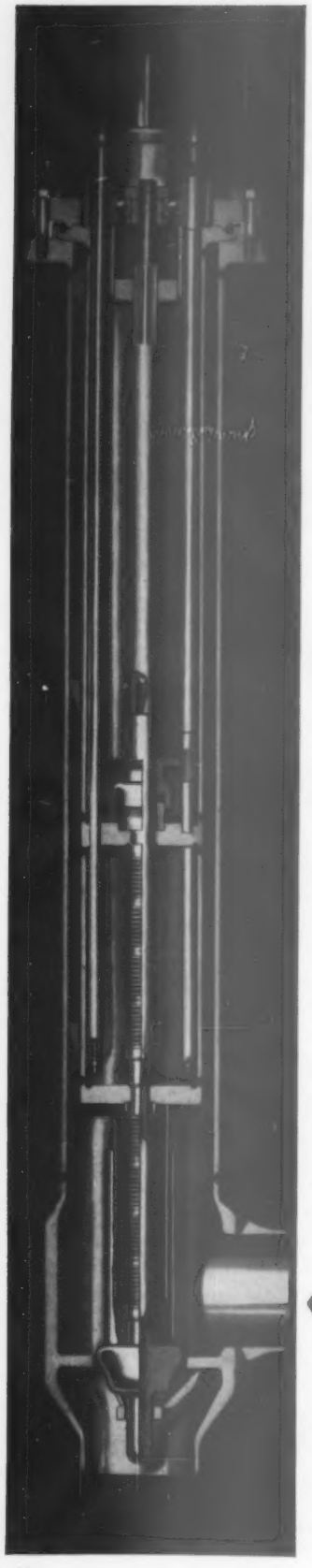

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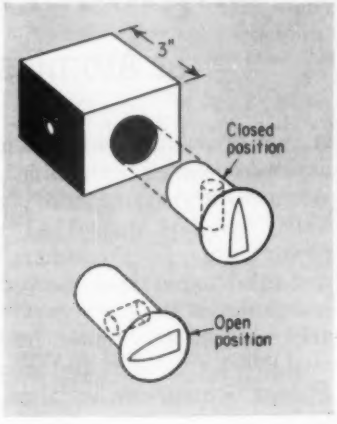

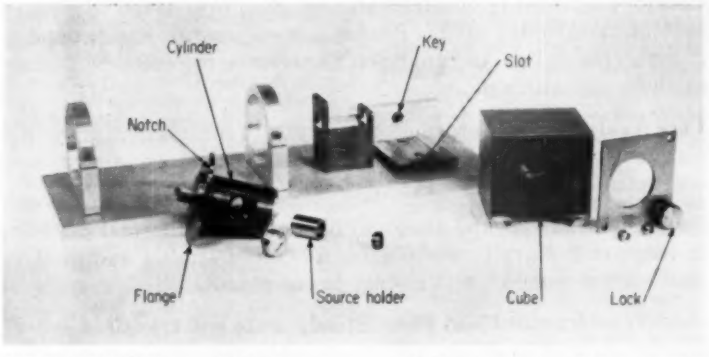

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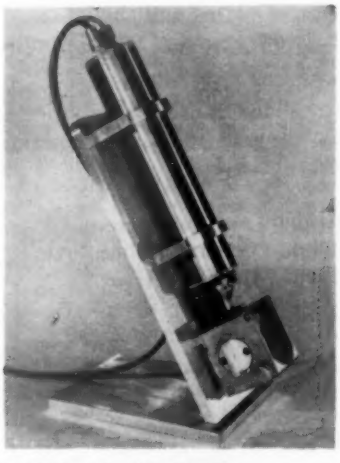

IN OPERATION holder is firmly locked on bracket by engagement of flange in slot. Cylinder must turn 90 deg to *closed* position for disengagement. Removal causes tumbler mechanism to lock cylinder *closed* until it is inserted on bracket once again or laboratory key is used to open it for bench use. Stops limit rotation to 90 deg. Holder is for gamma absorption measurements—or "absorptiometry" if you find it easier

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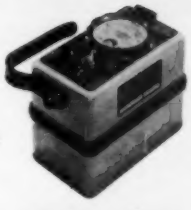

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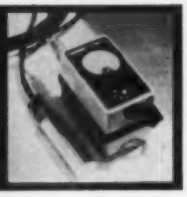

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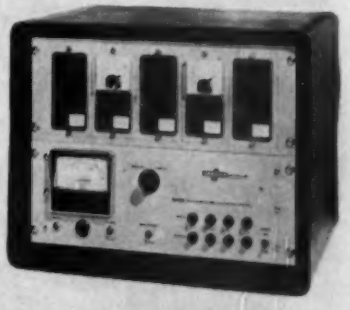

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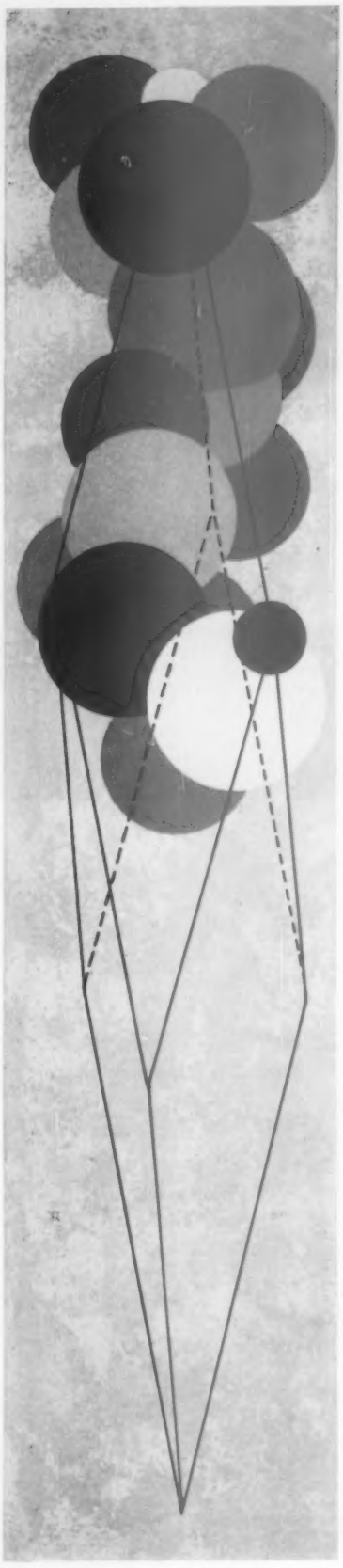

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This article starts on page 107

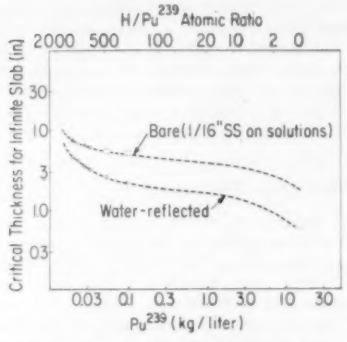

FIG. 5. CRITICAL THICKNESSES of infinite slabs can be used to estimate amount by which tank was subcritical before stirring

was evacuated. The time was 4:35 p.m., December 30.

The Burst

The initial action of the stirrer in the solvent-treating tank forced aqueous solution up along the wall, displacing the outer portion of the solvent layer and thickening the central portion. An average increase in solvent-layer thickness of ~0.4 in., corresponding to an average radius decrease of $\frac{1}{2}$ in., could account for the obviously supercritical configuration. The burst was certainly terminated by the violent disturbance that it generated, and continuation of the stirring diluted the plutonium beyond the point at which a critical reaction could recur.

Radiochemical analyses for Mo^{99} (concentrated mostly in the aqueous phase) indicate that the total number of fissions in the burst was about 1.5×10^{17}. This value may be subject to refinement when analyses for other fission products are complete.

Solution Removal

Immediately after the incident, a bank of ten 6- and 5-in.-diameter withdrawal cylinders was fabricated and set up about 100 feet from the point of the accident (Figs. 2 and 6). This storage array was connected to a transfer line that leads from the bottom outlet of the solvent-treating tank.

As the disposition of plutonium in the tank was then unknown, opening of the bottom outlet valve was a suspect operation, and therefore it was accomplished from behind a temporary shield with a 10-ft extension handle. The solution was vacuum-transferred into the bank of cylinders without complication on January 1. The solution level within the cylinders was followed by gamma-sensing instruments (maximum reading at contact was about 1 r/hr, and indications along the wall of the solvent-treating tank immediately after emptying were less than 50 mr/hr).

Analysis. Successive 9-liter lots of solution were removed from the storage cylinders, and each batch was sampled for chemical analysis. Results of analysis are summarized in Table 1. Not only was the bulk of the plutonium found in the organic solvent phase, but a concentration of Zr^{95} in a suspension at the aqueous-organic interface suggested that the situation was the same at the time of the accident. Furthermore, the chemical form in which the plutonium occurred in the solvent was consistent with the hypothesis that it had been complexed with TBP hydrolysis products.

Additional evidence that the plutonium

Special Committee Reviews Report

A technical report* describing the circumstances of the Los Alamos criticality accident has been made available by the Atomic Energy Commission. It has been written by the authors of this article and can be got at the Office of Technical Services, Department of Commerce, Washington 25, D. C.

General Manager A. R. Luedecke of the AEC appointed an investigation-review committee of AEC personnel to evaluate the report. On the committee were Marvin M. Mann, Division of Inspection, Clifford K. Beck, Division of Licensing and Regulation, Charles L. Dunham, Division of Biology and Medicine and Kenner F. Hertford, manager of the Albuquerque Operations Office.

The committee concluded that the accident was directly attributable to errors on the part of the operator who was killed. There has been some disagreement about how strongly the blame should be fixed. It has been established that the operator did not follow precisely the directions of his supervisor, who had outlined the procedure before the day's operations began.

The operator was an experienced man who knew the processes he was carrying out and the reasons for them. He had always followed directions and had a reputation for reliability. The manner in which he departed from the prescribed procedure led him to handle several batches of material together instead of one at a time. The altered procedure made for easier inventory and a neater process. The investigators feel that this may have been his motivation in making the alteration.

The committee found that closer supervision might have prevented the accident and commended Los Alamos personnel on measures they have taken to prevent a recurrence.

* H. C. Paxton *et al*, LANS-2293 (Feb. 20, 1959)

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13

Los Alamos Accident

This article starts on page 107

was concentrated in the solvent layer when the burst occurred is given by the long-lived gamma activity of the type-347 stainless-steel baffle located ~6 in. within the wall of the solvent-treating tank (Fig. 4). Scanning indicated a peak in activity about 1 in. below the mid-plane of the solvent layer.

Radiation Exposures

Results of radiation monitoring near the solvent-treating tank after the accident are summarized in Table 2. The fatally injured man received a radiation dose estimated at 12,000 rem ±50%. The next highest doses received by any of the operating personnel are estimated at 134 and 53 rem. Other exposures from the supercritical burst were less than 4 rem.

The chemical operator at the solvent-treating tank went into deep shock within 15 min of exposure. He regained consciousness about 6 hr later and remained rational and comfortable until nearly the time of his death at 3:15 a.m., January 1. The operators who went to his assistance show no physical effect of exposure other than typical changes in blood count in the the case of the man who arrived first and switched off the stirrer motor. Both have continued on regular duty. The fact that they received predominantly gamma exposure indicates, of course, that there was no succeeding burst while they were near the tank.

Nuclear-Safety Control

Ironically, a nuclear-criticality review of the entire plutonium plant had been completed about a month before the accident. Changes in equipment associated with a hopefully improved solvent-extraction process were planned so as to reduce dependence on procedural control of batch sizes for

FIG. 6. TEN WITHDRAWAL TANKS established safe geometry for vacuum removal of solutions after accident occurred

nuclear-safety purposes. This type of control had been used successfully during the 7½ years that the plant was in operation. Installation of the new equipment was scheduled for next June and July. Depending on efficiency of the new extraction process, the possibility of eliminating the succeeding raffinate solvent extraction and

TABLE 2—Results of Radiation Monitoring of Room 218

Date	Time	Dose rate r/hr	Distance from tank (ft)
Dec. 30	4:40 p.m.	20	25
	5:10	45	7.5
	5:15	0.2	110
	5:35	>50	4.5
	7:30	12	1.5
	9:45	0.1	25
Dec. 31	8:20 a.m.	0.05	25
	1:40 p.m.	10	Contact
	10:01	5	Contact
Jan. 1	9:00 a.m.	2	Contact

concentration stages (Fig. 1) was to be explored.

Because primary dependence had to be placed on procedural controls for a while longer, they were bolstered by re-emphasis and improved solids-sampling methods. Other measures undertaken were replacement of a product vessel for concentrated solution by one of safer geometry, review of operating procedures, improvement of the nuclear-safety training of personnel, design and installation of gamma-sensing radiation alarms, and updating of evacuation procedures.

The accident occurred in a process that was believed to be relatively safe because of small throughput. Long-term holdups of material, however, resulted from the requirement that certain plutonium accounts be balanced before material in other accounts could be processed. So, even here, procedural control was recognized as a safety requirement.

Since the accident there has been further detailed review of the entire plutonium plant. Additional or accelerated safety steps that resulted are:

- Design of geometrically favorable dissolvers and feed tanks for filtration and solvent extraction. This has been completed, and it is expected that the equipment will be installed before operations are resumed.
- Blocking of supplemental transfer lines. Lines like those required for emergency procedures will be blocked to minimize the opportunity for abnormal interchanges.
- Placing cadmium nitrate solution in vent tanks and vacuum-buffer tanks. This is to protect against criticality in case of accidentally introduced plutonium solutions. The use of both soluble and fixed neutron poisons in large process equipment is being studied, though unequal distribution between phases in the one case, and plutonium deposition on surfaces in the other, present difficulties.
- Calibrating and testing neutron detectors for indicating abnormal deposits of plutonium.

Previous Accident Reports:

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indscale, NUCLEONICS **15,** No. 12, 43
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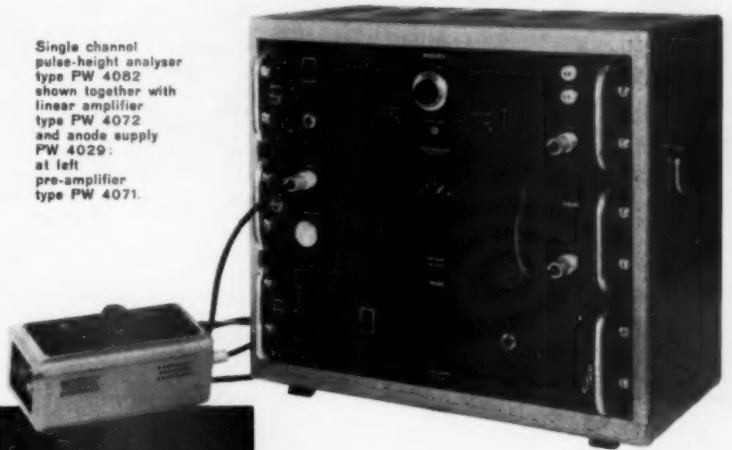

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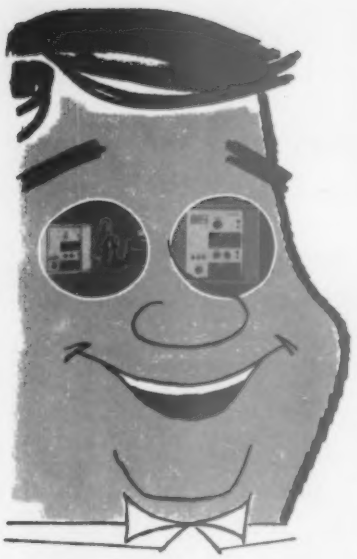

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Yugoslavian Accident

This article starts on page 106

the bare reactor received very strong doses of neutron and ionizing radiations. Two other persons, who were further away, also received radiation doses above the permissible level.

The irradiated persons received first aid at the Institute and all metal objects they had on their persons were taken away and retained. They were then transferred to the Center for Professional Diseases in Belgrade for treatment. The same day Professor Jammet, head of the Service d'Hygiene Atomique et de Radiopatologie of the Curie Foundation in Paris, was contacted and gave his consent to accept the heavily irradiated patients for treatment on his service. After the patients were checked and found to be free of radioactive contamination, they were flown the following day to Paris. One of those irradiated, the Student Zivota Vranic, died one month later—on November 15th—because of complications in the respiratory system and the gastro-intestinal tract. The history of the treatment as well as the methods used, will be reported by the doctors of the Curie Foundation. We would like to use this opportunity to express our profound gratitude and admiration for the heroism and self-sacrifice shown by the personnel of the Curie hospital in their fight to save the irradiated patients.

The two persons who received smaller doses of radiation were treated in the Center for Professional Diseases in Belgrade.

Investigation

A special committee appointed by the Chairman of the Federal Nuclear Energy Commission examined the causes which led to this accident. In addition to the statements of all persons present in the reactor building at the time of the accident, the commiftee collected data based on the following: the measurement of the induced activity of metal objects which were on the irradiated persons or in various places in the vicinity of the reactor; the data submitted by the radiation monitoring service; the measurement of the residual activity of the reactor core, and the results of the medical examinations. On the basis of these data and the facts established by the committee the following conclusions can be drawn:

(a) During the experiment on October 15th none of the normally used instruments for dosimetry, alarm and automatic safety control were turned on. The reactor became supercritical because of the uncontrolled rise of the heavy water level in the reactor tank.

The mechanism of controlling the heavy water level and the constructive details of the safety and signalization equipment are described in the article "Zero Energy Reactor RB," Bulletin of the Institute of Nuclear Sciences "Boris Kidrich," No. 9, page 5 (1959) [(4)], and the data contained therein will not be repeated here.

(b) The radiation monitoring equipment and the automatic release of safety rods were neither designed nor constructed as an interlock system so that it was possible to put the reactor in operation even if such

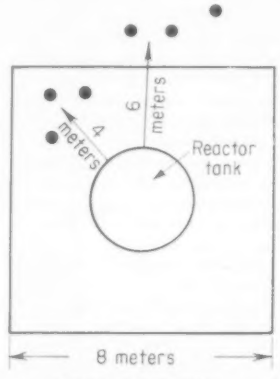

FIG. 4. EXPOSED PERSONS stood as indicated by heavy dots at time of accident. Two more much further away also received doses greater than permissible

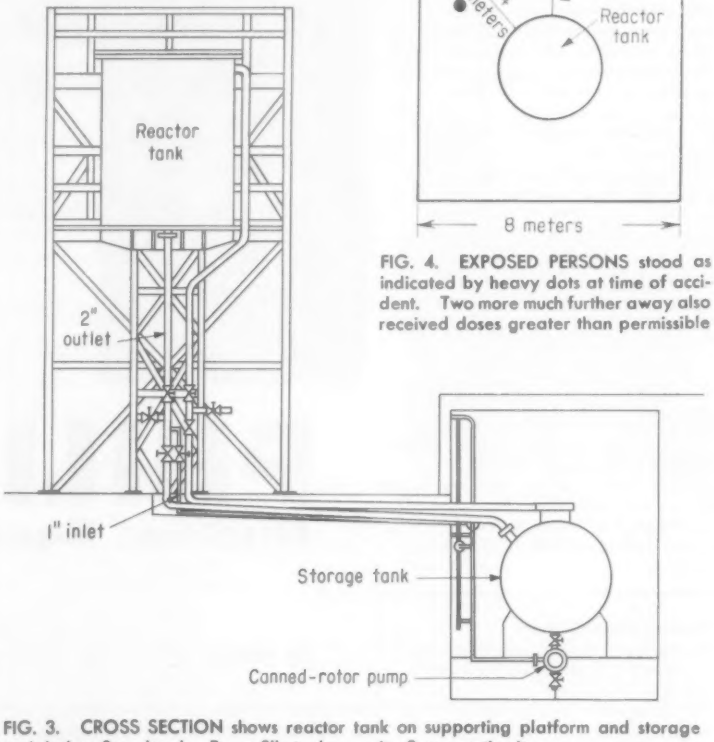

FIG. 3. CROSS SECTION shows reactor tank on supporting platform and storage tank below floor level. Pump fills tank; gravity flow empties it

equipment was removed or turned off.

(c) Under such circumstances, in the absence of signalling equipment and automatic shut-down of the reactor, the personnel first noticed an abnormal condition only by the smell of ozone formed in the air.

(d) An automatic recorder of the monitoring service for measuring air-borne activity and radioactive fall-out, 540 meters away from the reactor, registered the power rise and the accompanying gamma background for an interval of 10 minutes.

Determination of Doses Received

In order to determine the approximate doses of radiation received by those irradiated, the neutron induced activity of the copper and gold objects they had on their person during the irradiation or which were in the vicinity of the reactor, as well as the phosphorus in the urine was measured. The intensity of gamma radiation of Au^{198} (T = 2.7 days) and Cu^{64} (T = 12.8 hours) was determined by the scintillation spectrometer. The measurement of Au^{198} gave $(1.17\text{–}2.63) \times 10^{11}$ thermal neutrons per cm^2 and that of Cu^{64} $(1.19\text{–}3.03) \times 10^{11}$ thermal neutrons per cm^2. The activity of P^{32} in the urine, measured by a beta counter (method of solid angle) gave for the total flux 1.86×10^{11} thermal neutrons per cm^2. The mean value of the total flux of thermal neutrons was found to be 2.2×10^{11} thermal neutrons per cm^2.

From this value of the flux it can be taken that the energy produced by the reactor during the supercritical state was about 8×10^7 watt-sec. This value is in agreement with the results obtained from the measurements of radioactive decay of fission products since October 15th, 1958. From the reactor characteristics it is known that the diffusion area L^2 is equal to the neutron slowing down area. Therefore, the neutron leakage is the same in both the thermal and the epithermal region. From these data, which were first determined by calculation and later confirmed by experimentally measuring the migration length M^2, one can obtain, with an accuracy of 10%, the epithermal neutron flux

$$F_{ep} = (2.2 \pm 0.3) \times 10^{11}$$

epithermal neutrons per cm^2

Continued on next page

Characteristics of the Boris Kidrich Critical Facility

Reactor tank		
Inside diameter	199.86	cm
Wall thickness	1.0	cm
Height	230	cm
Fuel		
Diameter	2.5	cm
Length	210.00	cm
Aluminum cladding thickness	0.1	cm
Cladding purity	99.9%	
Total weight of uranium	3,995.0	kg
Lattice pitch (square)	12.0	cm
Moderator (heavy water)		
Maximum depth	208.00	
Critical level (22° C)	177.6 ± 0.1	cm
Total volume	6.36	$meter^3$
Safety rods (cadmium)		
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Distance from axis	30	cm

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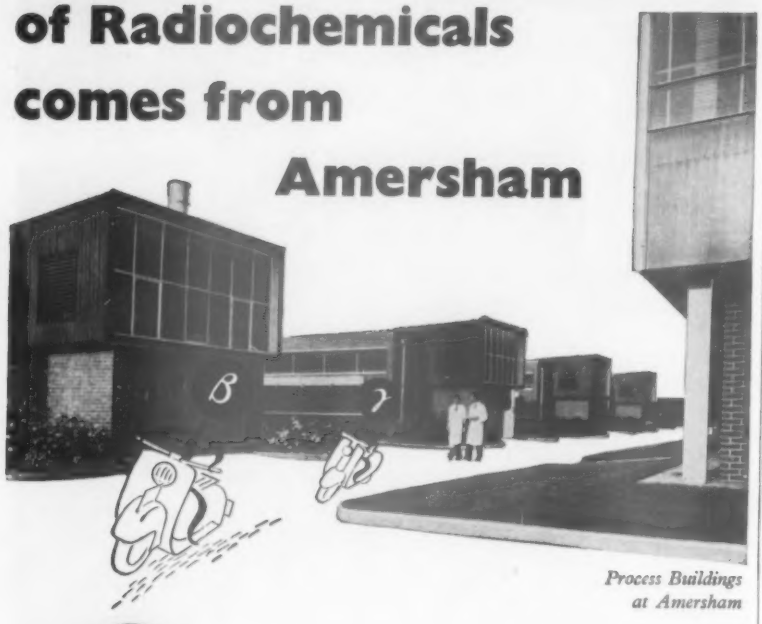

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Yugoslavian Accident

This article starts on page 106

On the basis of measurements made earlier during the normal operation of the reactor by a scintillation counter with "Hornyak," it was possible to find the ratio of neutrons above the energy level of 1 Mev and the thermal neutron flux determined by a proportional BF_3 counter and boron ionization chamber in the standard neutron flux. The ratio determined from these measurements is

$$F_{fast}/F_{therm} = (3 \pm 1) \times 10^{-2}$$

and

$$F_{fast} = (6.6 \pm 2.2) \times 10^{9} \text{ neutrons/cm}^2$$

On the basis of the above facts and the curves for depth dose of neutron irradiation according to Snyder [(5)] it can be calculated that the irradiated persons received the following average whole-body doses:

From neutrons with an energy level above 1 Mev

$$D_f = 116 \text{ rems}$$

From neutrons with energies between the thermal level and 1 Mev, calculating the spectral distribution by the $1/E$ law

$$D_{1/E} = 223 \text{ rems}$$

From thermal neutrons

$$D_{th} = 49 \text{ rems}$$

The total average whole-body dose absorbed from neutron radiation is

$$D_{tot\ neutr} = 388 \text{ rems}$$

It should be pointed out that the irradiated tissues and organs nearer the incident area of neutron flux received considerably larger local doses. Thus, for example, the average dose of neutron radiation for tissues at a depth of 10 cm is about 850 rems.

In earlier experiments it was found that in the area where the personnel were located the average dose rate of gamma radiation at a thermal neutron flux of 155 n/cm²/sec was 1 mr/h. On the basis of these findings it can be inferred that the irradiated persons received a gamma dose of 400 r or, if it is assumed that the mean energy of gamma rays is 3 Mev, the average whole-body dose received from gamma radiation is 295 rems.

Accordingly, the total average whole-body dose received by the irradiated persons from neutron and gamma radiation is

$$D_{tot} = 683 \text{ rems}$$

Since the irradiated persons were at different distances, the variation in individual dose from the average may be taken to be about 15%.

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Refrigerated Coils Show Fusion Promise

Cooling the windings that provide the confining magnetic field of a fusion reactor to temperatures close to absolute zero promises significant improvements in the design and perhaps the very feasibility of fusion power plants. Cooling can, for example, make possible thermonuclear plants in the range of 10–300 Mw rather than the few thousand megawatts that has characterized all net-power-producing fusion designs discussed to date. It can make possible the operation of fusion machines in a regime where the plasma energy is but a small fraction of the energy of the confining magnetic field—a situation that shows high promise of being stable.

Refrigerated windings have been considered often in the history of the Sherwood project, but it is only recently that the foregoing implications have been appreciated. This new understanding is due to Richard Post, leader of the mirror machine work at Livermore. First public announcement was made by Edward Teller in a talk at the recent New York meeting of the American Physical Society. Teller feels so enthusiastic about the promise of the new ideas that he has advanced his Geneva Conference prediction of economic fusion power "only in the next century," though he agrees with the general prediction that it is still a long time away.

The reason why magnet cooling can have such extensive effects is that in all fusion-power-plant conceptual designs a very considerable fraction of the power produced must be put back into the windings that provide the confining magnetic field. In fact, the reason why fusion-power-plant paper designs generally end up in the range of thousands of megawatts output is that only then do magnet losses become relatively tolerable. Cooling a magnet coil from room temperature to 12° K reduces its resistance by a factor of 1,000 with a corresponding decrease in the ohmic heating loss. The gain would be even greater if not for the fact that magnetoresistive effects become important at these low temperatures and result in no improvement being obtainable by going to temperatures lower than about 12° K. Of course a goodly part of the power thus saved must be turned over to the machinery necessary to refrigerate the coils, but a net gain of 25 still seems feasible. Formidable cryogenic problems are involved here, but it is felt that those can be solved without prohibitive capital-cost penalties.

The drastic reduction in power required to provide the magnetic field permits one to reduce the power output of the thermonuclear plant to as low as 10 Mw. Even more significantly it permits one to operate at low "beta," ratio of plasma energy density to magnetic-field energy density. A beta as low as 0.01 may even be practical. What's significant here is that low-beta devices tend to be more stable. As Teller points out, magnetic fields by themselves are stable; the more dilute the plasma the better the chance that it can live stably in the confining magnetic field for a sufficient time to permit a sufficient fraction of the confined deuterons to fuse. In fact Post's experimental mirror machines at Livermore, operating at betas up to 0.08, have already demonstrated stability for times of the order of milliseconds.

Of course Post's experiments to date have been at temperatures below 10,000,000°—there is still a factor of at least ten to go in temperature. No man would claim to be so wise in the ways of plasmas as to state categorically that no new form of instability will arise. Stability remains the number one problem in the forest that is Sherwood. Nonetheless there is enough promise in the new ideas involving refrigerated windings to insure that they will be pursued with vigor by the Livermore group. One idea that has them intrigued is to use sodium for the windings; it is available in even greater purity than copper and could more readily be annealed to remove resistivity-increasing effects of neutrons escaping from the fusion reactor. Sodium also has a lower magnetoresistivity coefficient than copper. In fact the encouraging numbers given here assume its use, though copper would also yield some of the advantages stated.

Note that the effect of these coil-refrigeration ideas is to shift some of the complexity of the mirror machine away from the immediate vicinity of the plasma at the expense of introducing a new and complex element—the cryogenic system. But cryogenics is better understood than magnetohydrodynamics, and if one can buy an answer to the as-yet-unsolved problems of plasma stability at the price of some complicated low-temperature engineering, it will be worthwhile indeed.

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BOOKS

Uranium and Thorium

By L. GRAINGER (Pitman Publishing Corp., New York, 1958, viii + 204 pages, $6.00)

Reviewed by W. R. THOMAS, Atomic Energy of Canada Ltd., Chalk River, Ontario.

The author has written the book "to present a reasonably comprehensive picture of the technology of uranium and thorium, from their occurrence and extraction, through their chemical and physical properties, to their uses in the atomic energy industry." It is intended specifically for "scientists, engineers and technologists associated with industrial organizations which are not primarily concerned with atomic energy but which are giving an increasing service to this new industry without perhaps, being given much background."

It is surprising that the author has achieved his aims in such a small volume, less than 200 pages of text, and succeeded in presenting a clear and readable account. He has written with the confidence and authority one expects from the former Chief Metallurgist of the Industrial Group of the United Kingdom Atomic Energy Authority (Mr. Grainger is now Chief Metallurgist at Harwell).

Descriptions of the extraction processes occupy roughly one-third of the book, with a slightly heavier emphasis on uranium, a feature that understandably persists throughout the whole book.

A brief chapter each on the chemistry of uranium and thorium is followed by rather more substantial chapters on physical properties. There is a brief reference to health hazards and, finally, a well written description of the uses of the metals as nuclear fuels and current practices in the fabrication of fuel elements, which occupies the remaining third of the book. These final chapters are enjoyable reading with topics ranging from reactor economics to the prediction of uranium requirements. Much of the information made available by the 1955 Geneva conference is summarized, and although summaries as such are not necessarily valuable, in this case the information is treated critically and its value enhanced by the author's contributions.

The book is not without faults. Specialists will complain, perhaps, of the cursory treatment given to their chosen fields. For example, irradiation damage of uranium takes four pages and the subject "*Thorium Fuels*" is dismissed in two pages. A strange penchant for italics creates stumbling blocks to the reader who searches for added significance that does not exist.

The book fills a definite gap in the literature, where there is still a lack of comprehensive texts on nuclear fuels. Readers on this continent can profit by appreciating the U. K. viewpoint and its approach to the use of uranium and thorium as reactor fuels.

The Physical Theory of Neutron Chain Reactors

By A. M. WEINBERG and E. P. WIGNER (The University of Chicago Press, Chicago, 1958, xii + 801 pages, $15.00)

Reviewed by Herbert Goldstein, Nuclear Development Corp. of America, White Plains, N. Y.

"Wigner's Group" has long since become a legend in reactor circles. From this fountain spring of reactor theory, first at "Met Lab" in Chicago and later at Oak Ridge, flowed the design calculations for our war time reactors such as X-10 and the Hanford production reactors. The work of the group in large measure set the pattern for most of the subsequent development of reactor theory in the U. S., and its former members are widely dispersed in positions of responsibility in the nuclear energy program.

For many years we have been sustained by rumors that the experience of the group would be crystallized in an authoritative treatise on reactor theory. Our expectations have now been magnificently fulfilled by this book.

The riches here unfolded to us may best be indicated by a brief summary of the contents. A short introductory chapter on the elementary concepts and classifications of reactors leads into a section of five chapters, totalling some 150 pages, on nuclear physics for reactor theorists. The topics considered range from the basic idea of cross sections through resonance reactions and the fission process to some of the latest theories in our developing picture of the nucleus.

Throughout these hefty (but necessary) doses of nuclear physics, the emphasis is on the applications to reactors. Thus, there are lengthy discussions on the calculation of fission-product poisoning and the possibilities of breeding. The chapter that then follows on nu-

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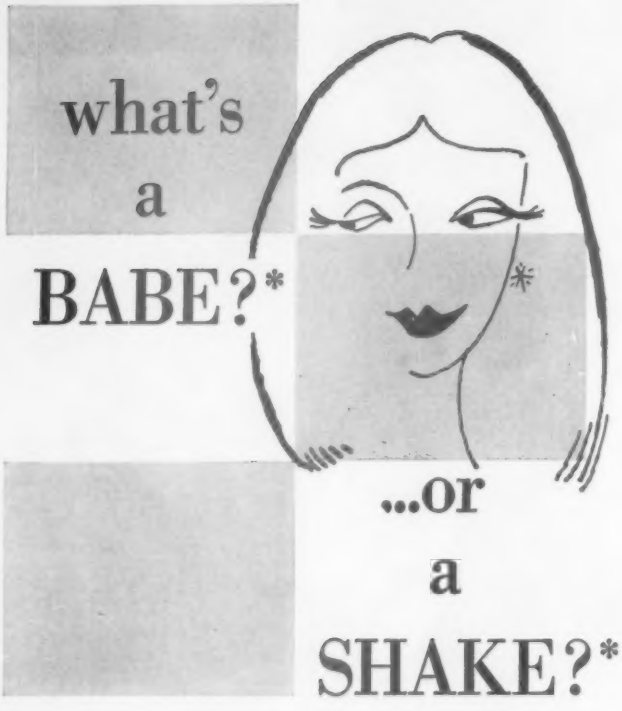

. . . . or a zerk?* or a jerk?*

These words are part of the scientific shorthand used at Los Alamos, where rapid advancement in nuclear research constantly requires new symbols. The Los Alamos Scientific Laboratory has openings for scientists and engineers interested in such fields as thermonuclear power, experimental fission reactors, nuclear rocket propulsion.

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clear-chain reactions serves to introduce basic concepts, such as criticality constant, multiplication factors, nonescape probabilities, etc., through the neutron-balance picture.

The transport and slowing down of neutrons are next discussed in four chapters of some 200 pages in all. Monoenergetic transport is treated first, then the space-independent slowing-down spectrum and finally combined moderation and transport. In each case, the procedure is to work up from the simple approximations, such as the diffusion and age theories, to the more exact treatments of the fundamental Boltzmann equation.

The next group of six chapters applies this information on neutron transport and slowing down (generally in the lowest approximation) to the study of the homogeneous reactor. Particularly, the first two of the chapters contain much that is new on the general theory of homogeneous reactors and will undoubtedly prove especially valuable. Topics such as temperature coefficients, reflector effects, perturbation theory and kinetics are also treated.

The final section of five chapters covers the theory of heterogeneous reactors, a subject that forms, as they remark, the authors' "first love." These chapters on thermal utilization, resonance-escape probability, fast effect, etc., are likely to be the standard source of information for some time to come. Particularly notable is the discussion of the resonance-escape probability, with its balanced treatment of both the "Western" method, originated by Wigner, and the method of attack described by the Russians at the first Geneva Conference.

Not the least of the memorable features in the book is the preface, which is a ringing avowal of faith by the authors in the importance of the "scholarly approach" to reactor physics. Some of the sentences should be cast in bronze plaques, preferably to be affixed to the office walls of budget directors and project engineers. Thus: "By a scholarly tradition, we mean the sum of historical, technical, and pedagogical doctrines . . . . which represent the deepest probing toward, the highest approximation to the truth." Again: "The practice of extrapolating from known cross sections without recourse to the underlying theory is, we believe,

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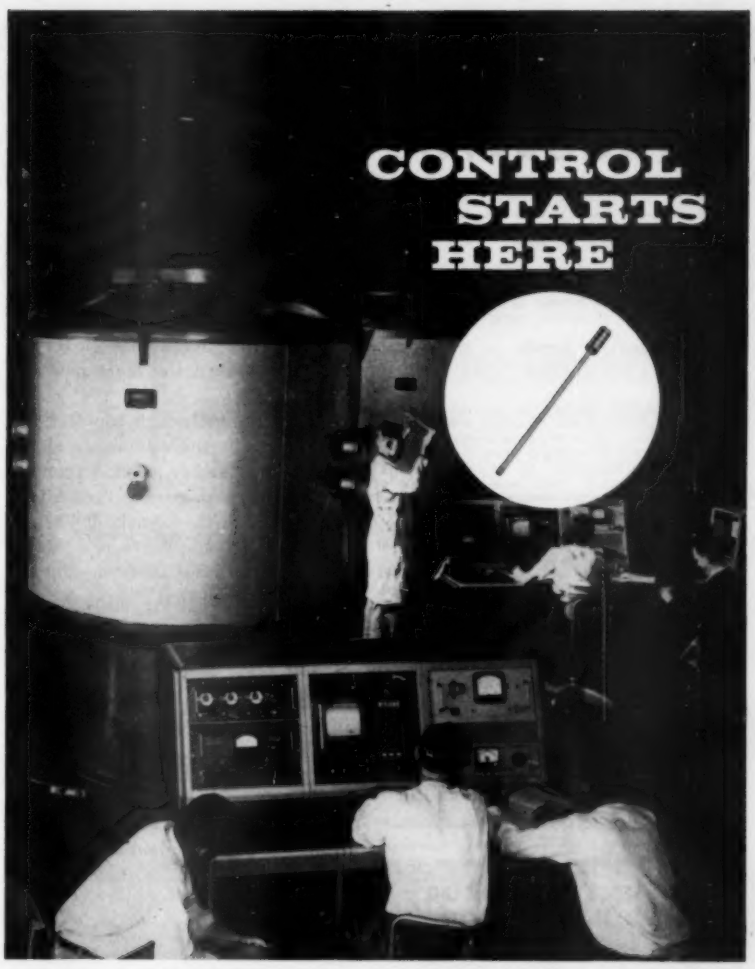
unsound. In this, as well as in all really creative thinking in reactor design, a working knowledge of nuclear reaction theory is required."

The explicit description in the preface of the authors' aims and the circumstances under which the book was written disarms any possible criticism of the subjects included and the manner in which they are treated. Thus, the authors state: "We do not consider the present book to be a complete account of reactor theory," and "Naturally, the book is much influenced by the thinking on reactor theory of our war time theoretical group at the Metallurgical Laboratory." It is therefore understandable that the emphasis is overwhelmingly on thermal reactors; only about 1% of the book explicitly considers the problems of fast reactors. Even within the field of thermal reactors, the problems arising from the wartime work, or ORNL's present interest in homogeneous reactors, receive fuller discussions than some others, such as kinetic effects. Other authors, with different experiences, might have changed the distribution of emphasis.

The authors also warn that: "We have tried not to make our book a handbook of criticality calculations. In particular, we have done less than justice to the many elegant machine-computing techniques that are now in vogue in many reactor centers, especially in the United States." The authors are certainly right in stressing that involved and lengthy machine calculations are no substitute for physical understanding. But the present-day ubiquity of multigroup and even fancier reactor computations cannot be denied, and the reader who is under the necessity of learning the details of their problems must look elsewhere.

The preface points out that: "This book has required a much longer time to complete than either author had anticipated; many parts have gone through several revisions." While the delay enabled the authors to refine a good deal of the text discussions, they were not able to escape completely the pitfall, so familiar to this reviewer, of incomplete revision. Chapter 6, for example, is an excellent exposition of changes wrought by the shell and optical models on our ideas of nuclear reactions. But, in Chapters 3 and 4, there is only surface cognizance taken of these changes, though they markedly affect the quantitative, if not qualitative, conclusions made there about resonance parameters and average



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BOOKS

Department starts on page 168

cross sections. The experimental situation in neutron cross sections is often rapidly changing and is particularly difficult to keep up with. It is no longer true, to cite one example from p. 101, that observation of gamma rays from inelastic scattering provides the best technique for studying the inelastic process. Fast time-of-flight analysis of the neutron energies has for several years now proved the more powerful tool.

In wandering through the sections, one is struck by the voluminous elaboration reactor theory has undergone in its short life of little more than fifteen years. Despite the formidable size and detail of the book, there is a liberal sprinkling of those awesome phrases "it can be shown that" and "detailed derivation leads to." This necessary compression results in the omission, for example, of the derivation of the age in a hydrogenous medium containing a nonmoderating element, and of the Wigner-Wilkins equation. It is particularly regrettable that no derivation of the last has yet found a home in the pages of some book, for the equation has been the basis of almost all thermalization work until recently, and only a skeleton derivation has been given in a report not generally available.

In one aspect, this reviewer must respectfully submit that the authors have done a distinct disservice to reactor physics in general. Out of an entirely laudable desire to do honor to Enrico Fermi, they propose to replace the "barn," representing 10^{-24} cm², by the "fermi." Little objection could be raised if this proposal were to meet with universal acceptance. The stature of the authors is so commanding, and the usefulness of the book so great, that there will undoubtedly be some who use fermi instead of barn. But most people will not; nuclear physicists, in particular, will be loath to surrender the already prevalent use of the fermi for 10^{-13} cm. The consequence will be a repetition on a minor scale of the Tower of Babel; where once physicists talked in a common term from Hanford even unto Siberia, there will now be separate tongues. And anything that tends to heighten further the unfortunate fence between nuclear physicists and reactor people is especially to be deplored. It is earnestly urged that the authors withdraw their suggestion and bow gracefully to the dictum (paraphrased from an entirely different field) that "the custom of the people is law."

One further specific comment may be made. It is to be regretted that a derivation of the effective doppler-broadened cross section is given that contains a number of assumptions both explicit and concealed. It probably takes less space to present a rigorous derivation that need be modified only in the last step to yield the conventional formula. That the present one is incorrect can be seen by noting that it does not leave a $1/v$ cross section unaffected by the doppler effect.

The hunting of misprints is one of the time-honored perquisites of a reviewer, and in order that this reviewer not lose his license for lack of activity, one or two may be mentioned. On p. 174 it is stated that the multiplication constants k and k^+ for finite reactors are always *less* than C, the criticality constant. It is clear from the context that it is meant they are always bigger than C. G. Goertzel has also pointed out that there are errors in the signs of the spherical harmonic form of the transport equation in cylindrical geometry, Eq. 0.57. On p. 93, Ba^{140} is quoted as one of the few long-lived, high-yield fission products. This statement apparently stems from a misprint in Walker's report (repeated in Table 4.10), which gave the half-life of Ba^{140} as 1.28 yr, whereas it is actually 12.8 d.

These comments are not intended to minimize in any way the magnificent accomplishment that Weinberg and Wigner have presented us. Their book is a great pioneering achievement that will undoubtedly stimulate the scholarly growth of reactor theory. If it may be permitted, the words of the preface should again be quoted: "We hope that other workers in the field will feel impelled to write books on reactor theory in which they present their point of view, in which they expound what they consider to be essential. What we hope most is that future authors on the subject will remember that they will be adding to the scholarly tradition and that true scholarship requires care, and time, and patience—commodities which are all too scarce in the hustling reactor business."

When these future books will be written, they will be judged by comparison with "The Physical Theory of Neutron Chain Reactors." Few will reach the level of this standard.

BOOKS RECEIVED

Study Abroad, Vol. X (UNESCO, Paris, 1958, 779 pages, $3.00, available from UNESCO Publications Center, N. Y.) This paperbound book lists approximately 75,000 scholarships, fellowships, travel grants and other types of awards offered for study abroad. The present volume contains for the first time the fellowship program of the new International Atomic Energy Agency. Nearly 200 fellowships are offered in fields directly relating to atomic energy. Each entry includes complete details on where to apply, who is eligible, field of study, length of course, amount of award, etc.

Ceramic Fabrication Process, edited by W. D. Kingery (The Technology Press, Massachusetts Institute of Technology, and John Wiley & Sons, New York, xi + 235 pages, $9.50). A comprehensive coverage of the processes is given by 22 authors.

Stainless Steel Fabrication (Allegheny Ludlum Steel Corp., Pittsburgh, 1957, iv + 384 pages). This book, which details common fabrication methods, is available upon request made on company letterhead.

Industrial Carbon and Graphite (The Macmillan Co., New York, 1958, iv + 630 pages, $25.75). This book contains the proceedings of a conference held in London in Sept. '57. Physical and chemical properties and fabrication are covered. A section is included on nuclear uses.

Junction Transistor Electronics, by R. B. Hurley (John Wiley & Sons, New York, 1958, xvii + 473 pages, $12.50). This book is written for the practicing engineer.

English-Russian, Russian-English Electronics Dictionary, (McGraw-Hill Book Co., New York, 1958, 943 pages, $8.00). This dictionary was prepared for the Department of the Army. There are about 25,000 terms in the English-Russian section and 22,000 in the Russian-English section. U. S., U. K. and U. S. S. R. sources were used. Included are electronic theory and applications and principal nuclear terms. Terms having no English equivalent are explained, and there is considerable cross-referencing.

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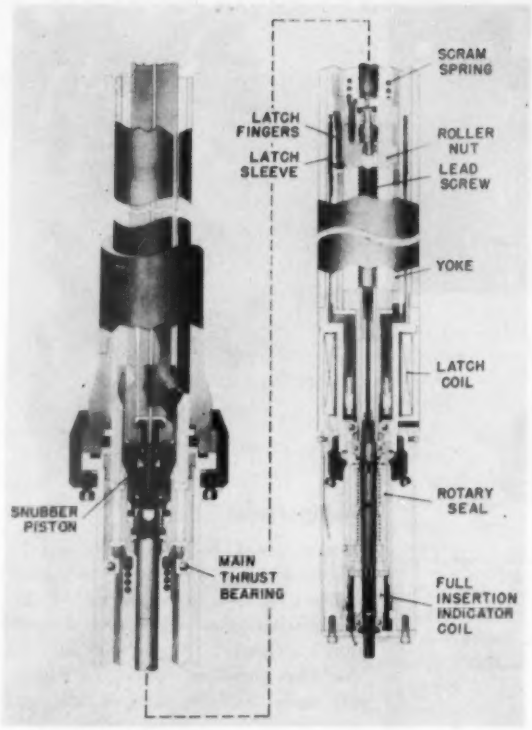

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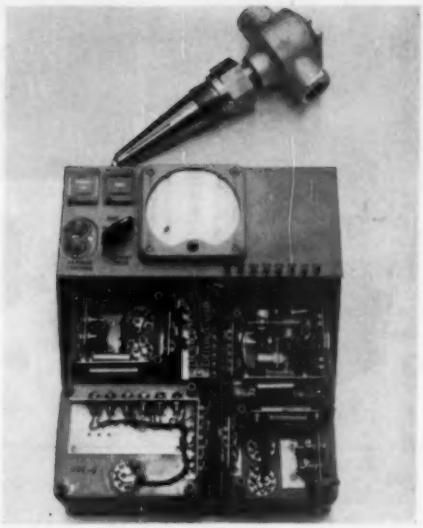

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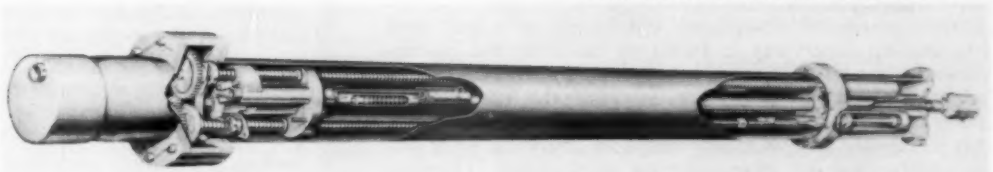

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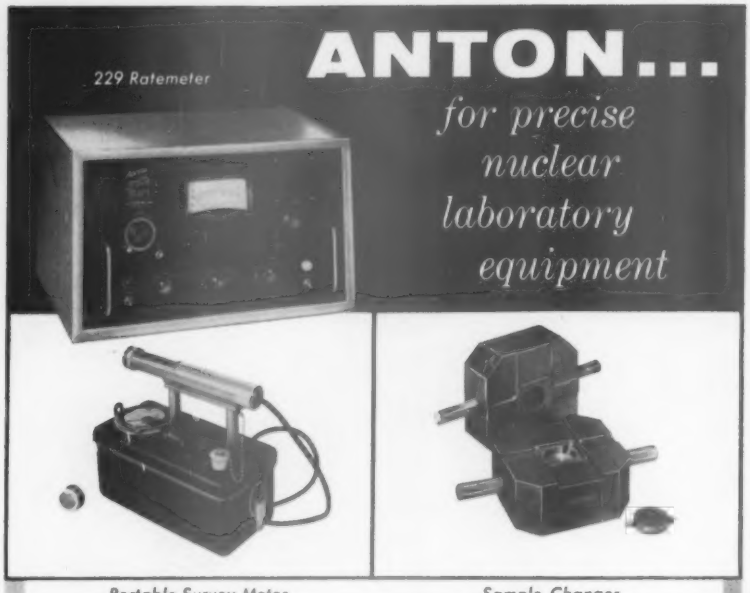
through a seal), the AMF drive (left above) can be top or bottom mounted, provide a wide range of rod speeds and be used at pressures up to 2,500 psi. This versatility is made possible by a simple lead-screw and roller-nut mechanism. The screw is coupled to the control rod and the nut is housed in a tubular yoke sealed within a pressure shell. The power and control units of the drive that are outside the pressure shell are built up entirely from commercial components.—American Machine & Foundry Co., 261 Madison Ave., New York 16, N. Y.

Hydrogen Analyzer

The Swartwout Co., in conjunction with Westinghouse, has developed an electric dissolved-hydrogen analyzer (right, above). This static, direct-reading, continuous analyzer requires only normal a-c power, and operates on the principle that palladium changes resistance in a predicatble manner in the presence of free hydrogen. The detector, containing a palladium sensing element and a platinum temperature compensating element on a zirconium oxide form, is installed directly in a sampling line of the piping. Resulting resistance changes are operated on by computers and amplifiers in the separately mounted readout unit where the concentration is displayed directly on an indicator. This unit reads over a concentration range of 0–100 cm^3 hydrogen per kg of water, with a temperature range of 400–600° F. —The Swartwout Co., 18511 Euclid Ave., Cleveland 12, Ohio.

Control-Rod-Drive Mechanism

This control-rod-drive mechanism (above) is designed for research (pool-type) reactors. A fail-safe scram latch is a magnetically operated one, and the scram spring is designed to meet stringent scram-time requirements. Four limit switches connected in series provide a 100% safety factor for the drive-motor control. In normal operation, a variable-orifice water buffer keeps forces on the core, control rod and supporting system to a minimum. Coasting or down-creep is controlled by an integral brake. Reversal time is 0–20 sec from full "In Positioning Rate" to full "Out Positioning Rate." Other features facilitate remote disconnection of the control rod from the scram shaft without draining the pool and easy electrical disconnection and lifting of the drive mechanism.—Vard, Inc., 2981 East Colorado, Pasadena 8, Calif.



Portable Survey Meter

Sample Changer

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For laboratory, industrial and field use, Anton offers a diversified group of instruments, all designed for speed, accuracy, efficiency and economy. Whether your requirements call for survey and monitoring instruments, ratemeters, special systems or control devices, we can supply units that have proven their superiority in numerous industrial and government nuclear installations. Typical of such instruments is the company's precision laboratory ratemeter—the first commercially available log-linear count ratemeter. This instrument has a recorder jack, is ideally suited for analytical work and is widely used for chromatogram applications. (Request Bulletin 59-I.)

For truly precise counting requirements Anton manufactures more than 100 varieties of neutron detectors, halogen quenched counter and integrator tubes, organic quenched, and other types of alpha, beta and gamma detectors. If your specific application is not covered by our tube catalog, we can develop detectors and systems to fill your need. (Request Bulletin 59-T.)

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PRODUCTS & MATERIALS

Department starts on page 166

Multipurpose Shield

Model US-1 multipurpose shield (above with flow-geiger counter) is designed to accept interchangeable G-M, scintillation, flow-geiger and proportional counters. Two inches of lead shielding surround detector. Standard model includes three sample and absorber slides; special slides are offered for manual and semiautomatic operation and for chromatogram strip counting. Slides accommodate either samples or absorbers with 1- or 2-in. diameters. Detectors have transistorized amplifiers and are interchangeable in 60 sec. Geometry control is accomplished by click-stop mechanism and scale, to indicate each cm of vertical movement, and slides spaced 1 cm on center.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Hot Rolling Mill

Model 122 two-high, reversing-rod mill is designed especially for hot rolling of tungsten and molybdenum. Equipped with 12-in.-dia by 24-in. special grooved rolls, mill will roll $2\frac{1}{8}$-in.-dia billets to both $1\frac{1}{4}$-in. dia at variable production speeds from 60 to 180 fpm. Special features include motorized screwdown with either simultaneous or independent infinite adjustment of each adjusting screw; forced-feed lubrication system; hydraulic roll lifters; and special running-in-and-out tables and guides. —The Fenn Manufacturing Co., Fenn Rd., Newington, Conn.

Ignitron Tubes

Model WL-5550 ignitron tubes have held off capacitor voltages of 10 kv.

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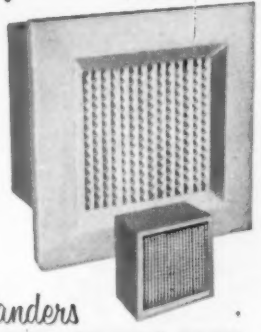

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AIRPURE CERAMIC FILTER

Flanders exclusive design provides AIRPURE filtration for very high temperatures and all atmospheric conditions. All new ceramic construction guarantees 99.95% efficiency on 0.3-micron-size particles and removes particles as small as 0.1 micron size.

All AIRPURE FILTERS are accurately tested to .01% for uniform high efficiency and the large capacity and low corresponding pressure drop mean top performance.

Flanders Ceramic Filters require little maintenance and are made of homogeneous materials which allow filter components to expand and contract uniformly, eliminating cracking between frame and media under high temperatures.

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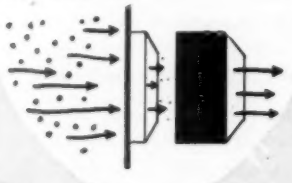
Even higher efficiency (99.97%) is available from the AIRPURE Filter Line—Removes particles as small as 0.1 micron size.



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Why Engineers and Architects Specify Liquid Tile Coating

Toughest Atomic Coatings Problems Solved By Evershield's Surface Coating Materials

From the architect's plans for the construction of a new atomic facility, to the modernization of older reactor areas, Evershield Liquid Tile has proven its economy and value.

Liquid Tile is a thermal setting, plastic resin. Applied as a liquid, it cures by internal heat into a vitreous-hard, totally unbroken surface. It is a 100% solids coating, totally free of solvents, and is completely non-porous and corrosion resistant. Since it may be applied without color, or in permanent, non-fading colors, it is therefore a highly versatile surface coating to be used wherever other coatings—including metals and ceramic finishes—fail or are otherwise undesirable.

Radiation Resistance

The characteristics of Liquid Tile make it particularly efficient wherever radiation resistance and ease of decontamination are necessary. This includes walls, pools and floor areas. **It has survived 10^9R without breakdown, enabling its use closer than other coatings to source materials. Its resistance to ageing provides lower overall costs. It is 100% waterproof and vaporproof, insuring maximum protection against leakage of contaminated water and fission material. It is easily decontaminated with ordinary soap and water. It is unaffected by intermittent exposure to extreme solvents through spillage, drainage and washing, and has survived boiling in 5% NaOh and 5% $H_2S^{\circ}4$ without effect.**

When used as a laminant with "fiberglas cloth," Liquid Tile provides complete protection against minor construction faults and shrinkage. Weight for weight, fiberglas-reinforced Liquid Tile is one of the strongest structural materials known, and resists tremendous loads and impact, such as are found in loading and floor areas.

Ideal Block and Wall Coating

Liquid Tile's basic characteristics make it an ideal wall coating for administrative areas in atomic facilities, such as in corridors and office spaces. It is easily applied by brush, spray or roller, in viscosities as thin as a varnish, or as heavy as whipped cream. Factory trained applicators can produce almost unlimited color tones, from soft pastels to multi-color effects that are particularly effective in hiding mortar joints and minor construction faults. The resulting surface is not only unbroken and practically maintenance-free, but also non-fading and abrasion-resistant. Sandblasting with #1 silica has failed to remove Liquid Tile from the coated surface.

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Martin Company—Maryland
Test Reactor—Babcock & Wilcox, Va.
ERCO Plant, ACF Industries, Maryland
Union Carbide, Oak Ridge
Los Alamos Scientific Lab
Decontamination Bldg.—Argonne National Lab
Physics & Metallurgical Hot Lab—Argonne National Lab
Argonaut Training Reactor—Argonne National Lab

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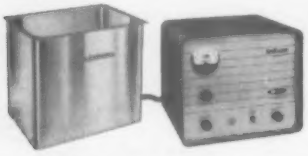

G-1501 generator, NT-1505 tank.

MAMMOTH 5-GALLON TANK $695

Other models from $175. 2-year guarantee on all units.

SPECIFICATIONS

Interior Tank size (in.), 10W x 14L x 9½H. Tank Capacity, 5 gallons.

Submersible Transducers

Model NT-604 — Hermetically sealed heli-arc welded stainless steel case. Radiating face: 27 sq. in. Effective plane of radiation: 40 to 50 sq. in. (approx. 10" x 5"). Effective cavitation of volumes: up to 1200 cu. in. at 24" tank height (5 gal.) and 2400 cu. in. at 48" tank height (10 gal.). Swagelok tube fitting on side or end for internal tank wiring.

Model NT-605 — Same as NT-604 except for bulkhead fitting on back for external wiring. Eliminates electrical conduits in solutions.

Now you can say goodbye to expensive chemicals, solvents, and degreasing equipment . . . reclaim valuable floor space . . . eliminate high installation costs . . . just by installing a Narda Series 1500 SonBlaster. At the same time, you'll get better, faster cleaning, and you'll need fewer people to do the job!

Get the tremendous activity of the new 200-watt Narda SonBlaster, with the largest transducerized tank ever made, at the lowest price in the industry! Choose from transducerized tanks or submersible transducers for use in any arrangement in any shape tank you desire. Up to 4 submersible transducers can be easily operated from the same generator at one time; load selector switch provided — an exclusive Narda feature.

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When ignitor is fired, currents from 30 to 45 × 10^3 amp are discharged. Discharge current is exponential in form with time constant of about 500 μsec. High-speed firing of ignitor is obtained by discharging 2-μf-capacitor charged to 1,500 v into ignitor, which fires in about 1 μsec.—Westinghouse Electric Corp., P. O. Box 2278, Pittsburgh, Pa.

Vibrating Capacitor

Vibrating capacitor (above) requires no shock mounts. Hermetically sealed steel housing is filled with inert gas. Magnetic driver unit is mounted outside seal and is completely shielded from capacitor assembly. Typical specifications are: capacitance, 20 μμf nominal; insulation resistance, 10^{14} ohms; contact potential, <25 mv positive or negative; contact-potential drift, $< \pm 0.2$ mv in 24 hr at constant temperature, <0.4 mv from 25 to 50° C, <10 mv drift in 1 yr; conversion efficiency, >12% ratio of a-c rms voltage output to d-c voltage applied at specified excitation; excitation voltage, 4 v rms, 50–200 cps, 25 ohms coil resistance.—Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Pulse Analyzer System

Portable, transistorized, 256-channel pulse analyzer system features plug-in logic. Main unit (Model CN-110 digital computer) contains magnetic-core memory, memory-current drive circuits, memory-cycle control binaries, address and arithmetic binaries, binary-to-analog converters, cathode-ray-tube display and power supplies. Plug-in units are available for pulse-height analysis (Model 210), neutron time-of-flight measurement (Model 211), pulse

neutron-decay measurement or any special program. Several data readout systems are provided for analog, binary, octal and decimal on strip chart recorders, X-Y recorders, printed paper tape, punched paper tape, punched cards and magnetic computer tape.—Technical Measurement Corp., 441 Washington Ave., North Haven, Conn.

128-Channel Scaler-Analyzer

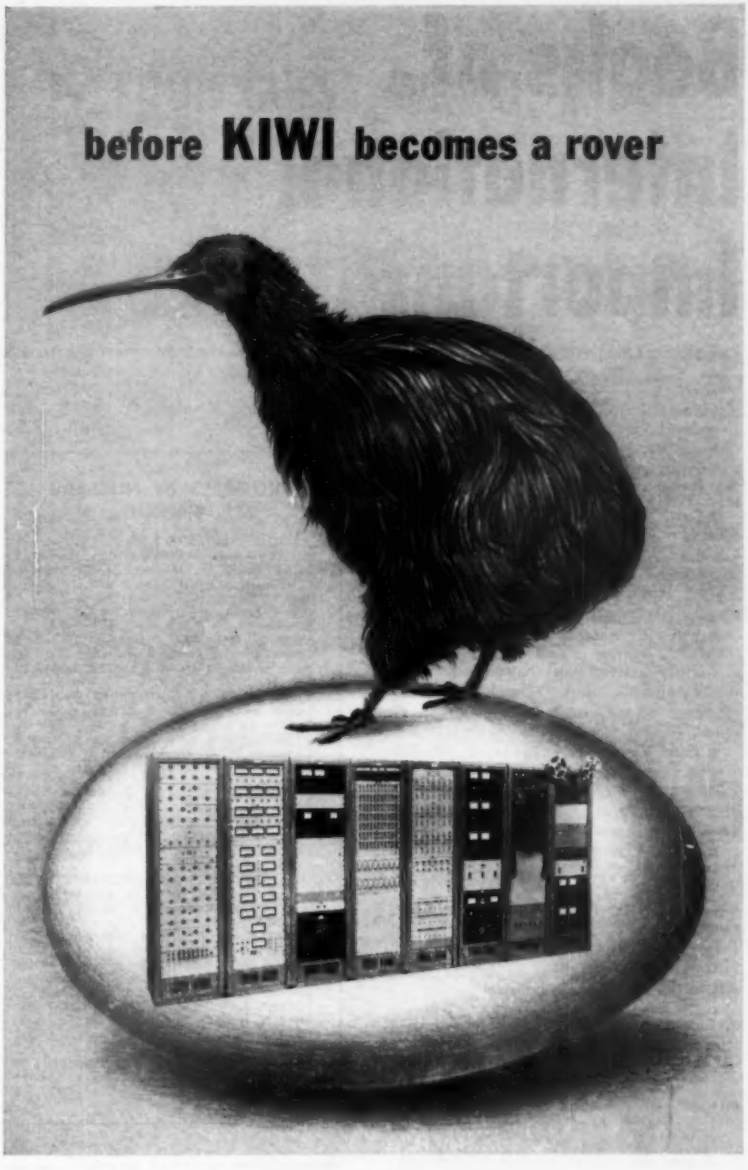
RCLiac-128 is a completely transistorized, integrated system. Compact (21 × 19 × 24 in.) instrument weighs 115 lb. Among features are: magnetic-core-memory capacity of 10^6 counts per channel; preset time from 0.19 sec to 28 hr; preset count from 2 to 2^{24}; 600–1,500-v negative voltage is stable to 50 ppm with well-regulated line; over-all amplifier gain of 1,000; integral linearity $< \pm 1\%$ for channels 5 through 128.—Radiation Counter Laboratories, Inc., 5121 W. Grove, Skokie, Ill.

Scintillation Detector

Model DS8 scintillation detector (above) provides detection of fast or slow neutrons, gamma and beta radiation with 10-stage, ¾-in. photomultiplier and transistorized circuits. Basic detector weighs <5 oz and has 1 in. diameter, is completely water-tight and corrosion resistant. Microsecond resolution time permits its use in high-radiation fields. Accessories include $1\frac{1}{32}$-in.-dia probe in which neutron-sensitive area is confined to end of 42-in. length so that "point" measurements can be made. Probe housing can be removed to substitute fast- or slow-neutron-sensitive phosphors. Three needle probes, 2–6 mm in diameter, for counting beta and gamma radiation have wall thicknesses of 2.5 mils and range in length from 10 to 15 cm.—Nuclear-Chicago Corp., 229 W. Erie St., Chicago 10, Ill.

Radiography Unit

"Tech/Ops" unit is 58-lb portable isotope machine that can be packed into case the size of overnight bag and per-



Project Rover is aimed at developing a nuclear-powered rocket engine that will result in man's conquest of intergalactic space. Kiwi-A is its first land-based test reactor, named for the flightless New Zealand bird.

Before Kiwi becomes a space rover, an immense amount of test information will be needed. Edgerton, Germeshausen & Grier, Inc., is cooperating with the AEC, NASA and Los Alamos Scientific Laboratory in collection of this vital data.

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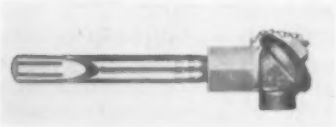


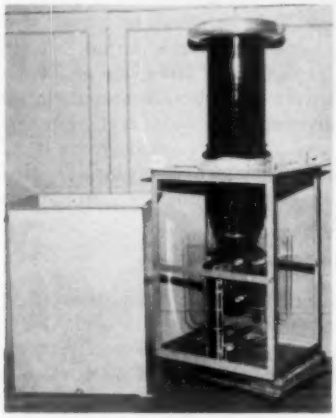
Thermocouple

PermaKouple heavy-duty, fast-responding thermocouple (above) consists of heavy (schedule 60) protecting tube containing two #8 B & S gage wires completely embeded in solid ceramic (aluminum oxide). PermaKouple will remain straight and rigid for indefinite period in temperatures up to 2,200° F.—E. C. Smith Mfg. Co., Forrest and Hector Sts., Conshohocken, Pa.

Liquid Scintillator

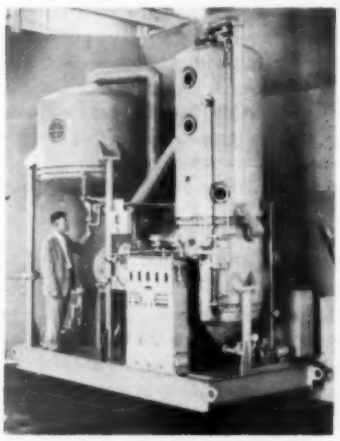
Type N612 scintillation counter (above) has been designed for assay of low-energy beta-emitting isotopes such as sulphur-35 (maximum energy 167 kev), carbon-14 (155 kev) and tritium (18 kev). Counter employs 13-stage photomultiplier followed by electronic amplifier with maximum gain of ×1,000. Light-tight shutter between glass sample container and photomultiplier window is interlocked with enveloping lid so that it is impossible to expose photocathode to extraneous light.

When operated with dynode voltage of about 120 per stage, and with whole instrument cooled to −20° C, counting efficiency for tritium is 10–20% with background of about 30 cps. With C^{14}, efficiencies of up to 100% are attainable, and it is possible to operate at ambient temperature.—American Tradair Corp., 34-01 30th St., Long Island City 6, N. Y.



200,000-PV Transformer

High-voltage transformer (above) features corona free operation and compactness. Unit is rated at 200,000 peak volts at 10 ma.—Del Electronics Corp., 521 Homestead Ave., Mount Vernon, N. Y.



Waste Concentrator

Radioactive-waste-disposal problem can be alleviated by concentration procedure that substantially reduces volume to be disposed. Key step in this procedure is removal of as much water as possible from wastes. Model SEE200KS (above) will process 200 gal of contaminated liquid wastes every

IS YOUR GUESS WORTH $100?

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In January, 1959 this standard production model single channel analyzer, selected at random, was placed in operation. Since that time it has been counting the 0.662 mev gamma of Cs^{137}. HOW LONG WILL IT OPERATE WITHOUT A FAILURE OF ANY COMPONENT INCLUDING VACUUM TUBES?

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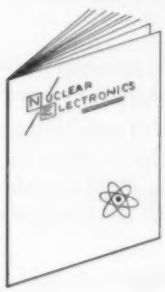

There will be only one winner. In case of ties, earliest postmark will determine winner. Entries become property of Nuclear-Electronics Corporation and must be received before April 11, 1959. Decision of the judges is final. Employees and representatives of Nuclear-Electronics Corporation are excluded.

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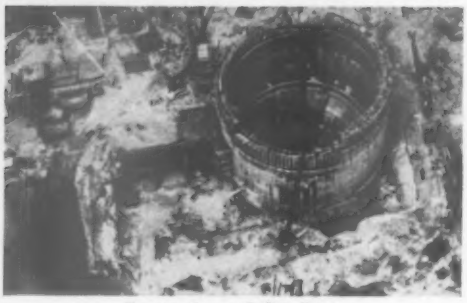

Construction at Indian Point

VITRO CORPORATION OF AMERICA has played a vital role in establishing many of the technological landmarks of the Atomic Age.

The latest—and one of the most significant—of these landmarks is a great nuclear power station now rising at Indian Point on the Hudson River. Beginning in 1961, this Indian Point station will pour 255,000 (net) kilowatts of electricity into the Consolidated Edison Company system.

Vitro Engineering Company, a division of Vitro Corporation of America, has served shoulder-to-shoulder with Con Edison and Babcock & Wilcox in developing this historic station. Its rôle began with the evaluation of reactor proposals, extended through preparation of all construction drawings and now includes assistance in the training of Con Edison's operating personnel for Indian Point.

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hour. It is fabricated of Inconel and stainless steel.—Mechanical Equipment Co., 861 Carondelet St., New Orleans 12, La.

Linear Accelerator

Linac is 6-million-volt linear accelerator for medical therapy and research that produces sharply defined beam of intense X-rays and can be converted to high-energy electron output. It has X-ray output of 200 r/min at 100 cm. Converted to electron output, it will deliver up to 500 watts at energies from 2 to 7.5 Mev. Electron beam is <5 mm in diameter at X-ray target.—High Voltage Engineering Corp., Burlington, Mass.

Ultrasonic Cleaner

Series 5000 SonBlaster consists of 40-kc, 500-watt-output, Model G-5001 generator and 10-gal-capacity, transducerized, Model NT-5001 cleaning tank. Series is capable of 1-min, or less, cleaning cycle for large assemblies or parts as well as big loads of smaller components. Stainless-steel cleaning tank ($20 \times 12 \times 11$ in.) is deep drawn to eliminate cracks and crevices.—The Narda Ultrasonics Corp., 625 Main St., Westbury, N. Y.

3-kw Ultrasonic Generator

Model APT-500 Sonogen generator (3-kw average power output) is designed for high-volume, all-day production cleaning and will activate up to 6 sq ft of transducer area or 300 gal of cleaning solution. Unit features motor tuning, twin-oscillator construction and remote control.—Branson Ultrasonic Corp., 40 Brown House Rd., Stamford, Conn.

Tritiated Titanium Targets

Thin films of tritiated titanium on stainless steel or molybdenum are produced by new process. Titanium coating is ~0.7 microns thick on 2-mil ticking and contains 1 c/in.^{2} of tritium. It is completely stable in normal atmospheres and is not appreciably affected by immersion in solvents or water or by exposure to acid fumes. Material produces ion current in excess of 10^{-7} amps/in.^{2} in air and absolute beta emissions $>10^{-9}$ amps/in.^{2} Absolute desorption rates of tritium and He^3 are <0.1 μc/c/day and 75×10^{-6} microliter/c/day.—Radiation Research Corp., 1114 First Ave., New York 21, N. Y.

LITERATURE AVAILABLE

Subject	*Length*	*Ask for*	*From*
Liquid scintillation counting	4 pp.	Abstract of proceedings	American Tradair Corp., 34–01 30th St., Long Island City 6, N. Y.
Neutron source	4 pp.	Bulletin PN	High Voltage Engineering Corp., Burlington, Mass.
Pumps	49 pp.	Catalog 5206	Nagle Pumps, Inc., Chicago Heights, Ill.
Thickness gage	11 pp.	"Raymike 600 Specifications"	General Electric Co., Milwaukee, Wis.
Neutron counters	4 pp.	"Neutron Counters for Reactor Control"	20th Century Electronics, Ltd., King Henry's Dr., New Addington, Surrey, England
Gaussmeter	4 pp.	Bulletin on Model G-501	Harvey-Wells Electronics, Inc., North St., Southbridge, Mass.
Zirconium tubing	4 pp.	Bulletin R-10	Tube Reducing Corp., 520 Main Ave., Wallington, N. J.
Aerosols	6 pp.	"The Aerosol Membrane Filter"	Gelman Instrument Co., 233 Jefferson St., Chelsea, Mich.
Methyl borate	—	Bulletin C-510	Callery Chemical Co., Pittsburgh, Pa.
Counting	4 pp.	"Control Engineering" reprint	Computer Measurements Corp., 5528 Vineland Ave., North Hollywood, Calif.
Connectors	—	"Amphenol Engineering News"	Amphenol Electronics Corp., 1830 S. 54th Ave., Chicago 50, Ill.
Image-converter camera	2 pp.	Brochure on Model C	Librascope, Inc., 66 S. "P" St., Livermore, Calif.
Servo valves	6 pp.	Catalog 220	Moog Valve Co., Inc., Proner Airport, East Aurora, N. Y.
Engineering design and consulting	4 pp.	Brochure on company	Internuclear Co., 7 N. Brentwood Blvd., Clayton 5, Mo.
Chromatograph accessories	2 pp.	Bulletin 1853	Consolidated Electrodynamics Corp., 300 N. Sierra Madre Villa, Pasadena, Calif.
Magnetic amplifiers	4 pp.	Bulletin 401-A	Acromag, Inc., 22519 Telegraph Rd., Detroit 41, Mich.
X-ray spectrograph application	4 pp.	"Rock Products" reprint	Phillips Electronics, Inc. 750 S. Fulton Ave., Mount Vernon, N. Y.
Radiation- and heat-resistant wire	8 pp.	"Ceramatemp"	Hitemp Wires, Inc., 1200 Shames Dr., Westbury, N. Y.
Counter tubes	—	Detector tube catalog	Anton Electronics Laboratories, Inc.
Neutron detectors	—	Data book	1226–38 Flushing Ave., Brooklyn 37, N. Y.
Glow tube scaler	2 pp.	Bulletin on Model 123	Baird-Atomic, Inc., 33 University Rd., Cambridge 38, Mass.
Instruments	36 pp.	Catalog A-1	
Instrument systems	36 pp.	Catalog A-2	

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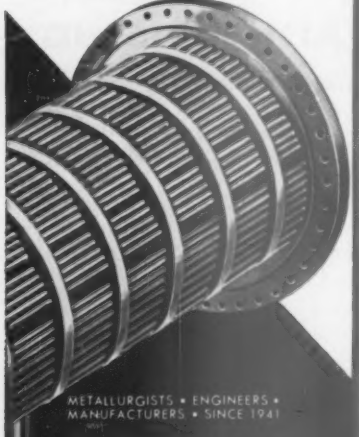

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INDUSTRY NOTES

• **Nuclear-Chicago** expects to be in new quarters at Des Plaines, Ill., shortly after mid-year. Half of the 250 × 200 ft building will house N-C's manufacturing and film-badge operations; the rest will house main offices, technical division and laboratories.

• **Metallurgical Products dept.** of **Clevite Corp.'s** Mechanical Research div. has announced the availability of design and production services for specialized titanium and zirconium components—based on the firm's recently developed high-density powder metallurgy processes.

• Powder metallurgy is the specialty of a new firm in Woodside, N. Y.—**Storchheim Research and Development Corp.,** 34-57th St. Storchheim will emphasize the development of new metallurgical materials, processes and products, as well as powder metallurgy techniques.

ACQUISITIONS. With the purchase of a large interest in **Heavy Minerals Co.,** Chattanooga, **Vitro Corp. of America** now has 87½% ownership of the rare-earths, thorium and heavy-minerals manufacturer; minority interest is held by a French chemical group. . . . **Biophysical Electronics,** Great Neck, N. Y., has acquired **Medical-Electronics Development Co.,** also of Great Neck. . . . **Curtiss-Wright** has assigned its new acquisition—**Inter-Mountain Instruments,** Albuquerque—to C-W's Electronics div., supplier of electronic and nucleonics devices.

EXPANSIONS. New facilities opened by **Tracerlab** include a $40,000 addition to its Reactor Monitoring Center at Richmond, Calif., and a southeastern sales office at Atlanta, Ga. . . . **Fenn Mfg.,** Newington, Conn., has formed a nuclear products div. under James P. Gantley and A. T. Scattergood, vice-presidents; the division will manufacture reactor components under sub-contracts. . . . Demand for tantalum in its high-purity and alloy forms by the nucleonics and other industries has prompted formation of a metals div. by **National Research Corp.;** the division will also produce other rare metals and related chemicals. . . . **Union Carbide Metals** has tripled the vanadium capacity of its Fine Metals and Chemicals dept., Niagara, to meet increased demand from nuclear and other users. . . . **Byron Jackson Pumps, Inc.,** Los Angeles, has placed a special "clean room" in service for final assembly of nuclear and cryogenic pumps—1500 sq ft.

AGENCY NEWS. New representative in Washington, D. C., for **General Instrument,** Newark, and **Electronic Tube,** Philadelphia, is **A. H. Fogelman Associates,** established recently to aid nucleonics, electronics and missile manufacturers to establish themselves as government contractors. . . . **Ridgway Engineering,** Chicago and Indianapolis, is sales representative for **Baird-Atomic** in Indiana, Illinois, Wisconsin, Western Kentucky and Eastern Iowa (handling transistor testing and semiconductor testing equipment). . . . **Tracerlab** is exclusive representative in the nuclear field for **Schmid Instrument's** constant volume air particle sampler. . . . **George H. Birchall Co.,** Westfield, N. J., is the new New York and northern New Jersey representative for **Ohmart** Nuclear Gages.

NEW BUSINESS. A contract for more than 120,000 enriched-U dioxide fuel pellets has been placed with **Nuclear Materials and Equipment Corp.** by **Sylvania-Corning Nuclear** for the Northern States Power Reactor, Sioux Falls, N. D. . . . Numec also has an order from **C. A. Parsons,** U. K., for high-density U-oxide shapes. . . . AEC has given a $50,500 contract to **Gladding, McBean & Co.,** San Francisco, for research and development on ceramic fuel elements. . . . **Controls for Radiation** has a contract from the Air Force Cambridge Research Center, Mass., for all nuclear radiation protection services required at the Center. . . . A $6,130,000 contract to build a major addition to Oak Ridge National Lab has been awarded **J. A. Jones Construction Co.,** Nashville.

FINANCIAL. Sales and earnings were up in 1958—23% and 19%, respectively—for **Metals & Controls Corp.** and **M & C Nuclear,** subsidiary; the increased sales from 1957 were accounted for primarily by rising business of M & C Nuclear, according to C. J. Thomsen, president. . . . Stockholders of **Metals & Controls** and **Texas Instruments** vote this month on the proposed merger of the two (NU, Feb. '59, 22); M & C stockholders will vote April 10, TI stockholders April 15.

NUCLEAR CAMPUS

• **Campus Facilities.** National Science Foundation grants for the aid of reactor construction have gone to **Texas A & M** ($350,000) and **Georgia Tech** ($750,000); NSF aid supplements that supplied by AEC's Reactor Development Div. . . . Georgia Tech has recently opened a $500,000 radioisotopes and bioengineering lab. . . . **McMaster Univ.,** Canada, will dedicate its research reactor April 10—Canada's first campus reactor. . . . **Univ. of Florida** is ready to go into operation with its Argonaut-type, 10 kw reactor. . . . Two New England schools plan reactor acquisition: **Worcester Poly** has agreed to the purchase of a 1 kw pool reactor from General Electric; **Lowell Tech** has completed specifications for a nuclear education-research center, though no dates have been announced on a construction start. . . . **North Carolina State College** has completed installation of a 1-mev Van de Graaf accelerator, expects completion of a 10-kw research reactor this fall. . . . **Wayne State Univ.** plans a lab course in nuclear physics beginning this fall and one in radiochemistry in the spring semester—both made possible by $51,378 in equipment-grant money from AEC.

• AEC has made the first of its equipment grants under the Isotope Development Program (Feb. '59, 29)—to the **Univ. of California,** Berkeley ($80,000). The money will support equipment purchases for three new courses: a 10-week study program for industrial scientists and engineers; a one-week survey course for executives; and a two-week course for regulatory officials. AEC has another $400,000 available for grants through June 30.

Courses

A seminar on **research-development uses of radioisotopes and reactors** will be held June 1–26 at Penn State. Contact Extension Conference Center, PSU, University Park, Pa.

Special radiation procedures in the treatment of cancer is offered by Queens Hospital Center, New York City, for one week beginning Sept. 14. Contact Philip J. Kahan, QHC, 82–68—164th St., Jamaica 32, N. Y.

MIT is offering several nucleonics courses under its special summer program, including **plasma dynamics,** a three-week course covering controlled fusion and other plasma fields; it runs Aug. 17–Sept. 4. Contact Prof. James M. Austin, MIT, Cambridge 39.

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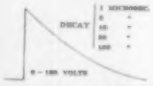

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on pages 54-55

NEWSMAKERS

William Eells, until recently coordinator of atomic energy for the State of Ohio (NU, Feb. '59, 26), has established himself in the consultant's business "on the state and local implications of nuclear development"—54 Elmwood Dr., Delaware, Ohio.

Oliver Townsend, second in command at the Atomic Industrial Forum staff since its organization in 1953, has resigned. A former special assistant to the late Gordon Dean when he was an Atomic Energy Commissioner, Townsend was one of the original two-man staff at AIF; the other was Charles Robbins, who remains executive manager. Townsend held three posts when he left AIF early in March: asst. executive manager, secretary, and editor of the Forum Memo. **Robert Barlow** succeeds him as Memo editor but no successor has been named for the other posts. Meanwhile, **Malcolm R. Tait,** Bankers Trust Co., has been elected treasurer of the Forum.

Townsend

Marvin Fox, a nuclear scientist for well over 15 years, has resigned his vice-presidency at Internuclear Co. to join the technical staff at Atomics International. Fox directed foreign operations at Internuclear, including its consultant services on the SENN project (Società Elettronucleare Nazionale). At various times since 1942 he has been at Massachusetts Institute of Technology (Radiation Lab), Manhattan District, Brookhaven National Lab and serving AEC as part-time consultant on safety.

Fox

General Electric has appointed **W. J. Love** of the Univ. of Denver and Denver Research Institute to consulting mechanical engineer on the new production reactor (NPR) at Hanford Works. NPR is in final design and an early construction start is scheduled. Love worked at both Hanford and GE's commercial facility, San Jose, Calif., before he went to Denver.

Another new consultant at GE is **Robert S. Shane,** an engineer on materials, materials applications and radiation effects on materials in the Defense Electronics div. Shane joined GE from Bell Aircraft where he was nucleonics specialist, rocket div.

AEC's deputy research director, **Paul W. McDaniel,** has been designated one of the ten top career men in the federal government for 1959. The award was made by the National Civil Service League. Another selection was **Richard W. Weiss,** scientific director of the Army's Research Office, who has been active in nucleonics, optics and electronics. McDaniel was instrumental in creating the controlled-fusion program at AEC.

Martin Co.'s nuclear div. has named **Clare P. Stanford** of Westinghouse to run its engineering dept.; Stanford held an advisory post at Westinghouse before joining Martin. Succeeding **J. A. Hunter,** now vice-president for engineering at Martin, Stanford will supervise all engineering projects at Martin-Nuclear—including reactor systems, radioisotope-fueled generators and propulsion work.

Stanford

In export-sales management changes at American Machine & Foundry, **Matthew S. Stolarz** has been appointed assistant general manager for all export sales, including nucleonics products, and **Seymour Oestreicher** has been named export sales manager for AMF Atomics, the nuclear div. Oestreicher designed the firm's "unitized" control-rod drive mechanism.

Robert J. Magill, a specialist in radiation-dosimetry methods, has been selected by Nuclear-Chicago to direct research and development on its nuclibadge service. N-C's **John L. Kuranz,** vice-president, has been appointed to AEC's Advisory Committee on Isotope Development.

Kevin G. Shea has joined Curtiss-Wright's Princeton div. as senior scientist in the nuclear radiation dept., working on the food-irradiation program underway for the Army and con-

sulting on radiation applications for industry, generally.

One of the nation's authorities on radiation calibrations and radiation effects on materials, **Frank H. Day,** has joined Victoreen Instrument as radiological physicist and head of the nuclear standards dept. Day was in charge of gamma and x-radiation calibrations at the National Bureau of Standards; he will design medical, x-ray and radioisotope instruments for Victoreen.

Day

Picker X-Ray Corp. has elected **John K. Dunn** president of three affiliates: Picker X-Ray of Iowa, Picker X-Ray of Nebraska and Picker X-Ray Midwest. **E. L. Gray** has been elected vice-president, Picker X-Ray Rocky Mountain, Inc.

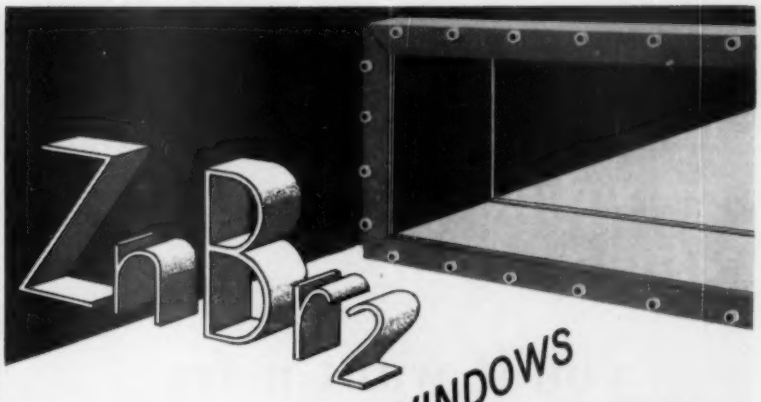
Ralph W. Waniek of MIT (Boston College lecturer) and Harvard (working with the Cambridge Electron Accelerator) has taken over direction of the new Magnetohydrodynamics Lab of Giannini Plasmadyne Corp.

Lewis M. Branscomb, chief of the atomic physics section, National Bureau of Standards, has been given the Washington Academy of Sciences award for outstanding scientist achievement in the field of physical science. He was cited for "distinguished contributions to the physics of negative ions."

A veteran of the *USS Nautilus* reactor effort at Westinghouse, **Robert A. Bowman,** has been elected vice president of Bechtel Corp. Bowman was engineering manager of Bechtel's power and industrial div. before his election; before that he spent 20 years with Westinghouse, leaving as engineering manager, atomic power div., after contributing to the naval reactor program.

Bowman

Robert Louis Jordan has been named employee relations manager, General Electric atomic power equipment dept.



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NUCLEAR CALENDAR

Apr. 2–3—Conference on Electrically Exploded Wires, sponsored by the Air Force Cambridge Research Center, Boston (*Somerset*). Contact W. G. Chace, Thermal Radiation Lab, CRZCM, Geophysics Research Directorate, AFCRC, Bedford, Mass.

April 5–10—5th Nuclear Congress and Atom Fair, Cleveland (*Public Auditorium*). Contact T. A. Marshall, Jr., Engineers Joint Council, 29 W. 39th St., New York 18.

Apr. 5–10—American Chemical Society's 135th national meeting, Boston (*several hotels*). Contact Otto H. York, Otto H. York Co., West Orange, N. J.

April 6–8—Annual Convention, Edison Electric Institute, New Orleans (*Roosevelt*). Nuclear panel April 7. Contact EEI, 750 Third Ave., N. Y. 17.

April 26–May 1—20th Meeting of American Industrial Hygiene Assn., Chicago (*Sherman*). Three radiation sessions. Contact Elmer Wheeler, Monsanto Chemical Co., Lindbergh & Olive Street Rd., St. Louis 4, Mo.

Apr. 27–30—International Symposium on the Physical Chemistry of Process Metallurgy, sponsored by Metallurgical Society of the American Institute of Mining, Metallurgical and Petroleum Engineers, Pittsburgh. Contact J. F. Elliott, Mass. Institute of Tech., Cambridge 39, Mass.

Apr. 30–May 1—First National Youth Conference on the Atom, Atlantic City. Speakers include AEC Chairman John McCone and Norman C. Hilberry, director of Argonne National Laboratory. Contact Bozell & Jacobs, 2 West 45th St., New York 36, New York.

May 6–8—1959 Electronic Components Conference, sponsored by Institute of Radio Engineers, American Institute of Electrical Engineers, Electronic Industries Assoc. and West Coast Electronic Manufacturers Assoc., Philadelphia (*Benjamin Franklin*). Papers on instrumentation and control devices and radiation effects. Contact Bernard Osbahr, Electronic Industries, Chestnut & 56th Sts., Philadelphia 39.

May 11–12—Symposium on the Industrial Uses of Radioisotopes, Atlanta, sponsored by Georgia Tech, Lockheed and AEC. Contact Richard Wiegand, Georgia Tech, Engineering Experimental Station, Atlanta.

May 11–14—Management Conference of Organization of European Economic Cooperation on Industrial Prospects for Nuclear Energy, Stresa, Italy (*Palais des Congres*). Contact F. Aley Allan, Atomic Industrial Forum, 3 E. 54th St., New York 22, N. Y.

May 13–14—First Industrial Radiation Conference sponsored by the State of Kentucky, Louisville (*General Electric Appliance Park*). Contact Norman E. Schell, Dept. of Public Health, 630 S. 3rd St., Louisville.

May 14–15—Symposium on Nuclear Power, sponsored by Univ. of Vermont and American Institute of Electrical Engineers at Burlington, Vt. Contact AIEE, 33 W. 39th St., N. Y., N. Y.

May 18–19—Symposium on Radiation Chemistry of Gases in conjunction with annual meeting of Radiation Research Society, Pittsburgh (*Penn-Sheraton*). Contact E. L. Powers, Argonne National Laboratory, Box 299, Lemont, Ill.

June 1–3—Seminar on Radioactivation Analysis, Vienna. Contact A. I. Galagan, IAEA, United Nations, N. Y., or IAEA, Vienna.

June 1–3—Seminar on Atomic Hazards, sponsored by American Management Assn., New York. Contact Course Registrar, AMA, 1515 Broadway, N. Y.

June 8–11—American Rocket Society semiannual meeting, San Diego. Session on nuclear propulsion. Contact Stan Gunn, Rocketdyne, 6633 Canoga Park Ave., Canoga Park, Calif.

June 9–11—Conference on Safeguards for Radioactive Materials at Canisius College, Buffalo, N. Y. Co-sponsored by Canisius and N. Y. Dept. of Labor. Contact Herman A. Szymanski, Canisius, Buffalo.

June 14–18—Semiannual meeting American Society of Mechanical Engineers, St. Louis (*Chase-Park Plaza Hotels*).

June 15–17—Annual meeting of the American Nuclear Society, Gatlinburg, Tenn. Contact Octave J. DuTemple, John Crerar Library, 86 E. Randolph St., Chicago 1.

June 15–20—Congress on Nuclear Energy, sponsored by National Committee for Nuclear Research, Rome, Italy (*Palace of the Congresses*). Scheduled in conjunction with 6th International Exhibition on Electronics and Atomic Energy in Rome, June 15–July 5. Contact Evandro Benvenuti, via della Scrofa 14, Rome.

June 18–20—Fourth Annual Meeting of Health Physics Society, Gatlinburg, Tenn. Contact G. T. Saunders, Kewaunee Mfg. Co., Adrian, Mich.

June 18–20—Society of Nuclear Medicine, Chicago (*Palmer House*). Paper abstracts due March 1 to Donald W. Petit, Univ. of Southern California, School of Medicine, 1200 N. State St., Los Angeles 33.

June 24–26—2nd Nuclear Instrumenta-

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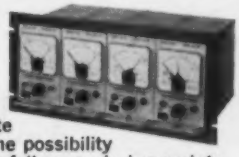

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July 17—9th Annual International Conference on High Energy Nuclear Physics, International Union of Pure and Applied Physics, Moscow. Contact Robert E. Marshak, Univ. of Rochester, Rochester, N. Y.

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Rudolf E. Slovacek is one of a number of KAPL scientists concerned with reactor physics. He earned a BSEE at Union College in 1945, joined KAPL in 1951 after taking his MS in Physics at Indiana University. Since then he has contributed to several KAPL projects.

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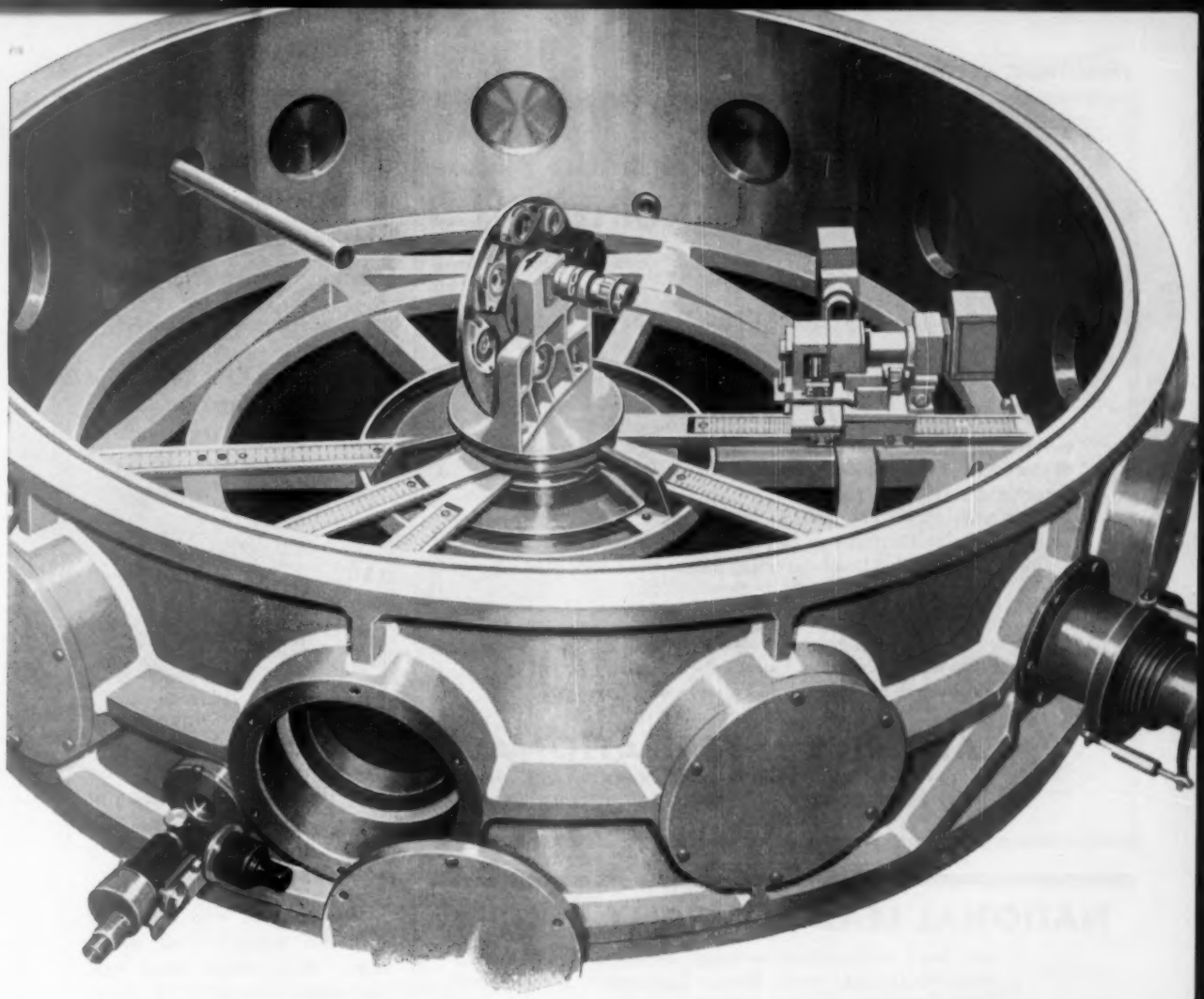

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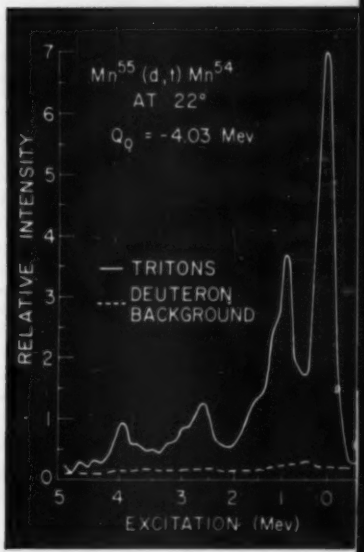

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INDEX TO ADVERTISERS

APRIL 1959

ACF Nuclear Products-Erco Div. of ACF Industries, Inc. 115
Advertising Council 159
Allegheny Ludlum Steel Corporation 69
Ameray Corporation 74
American Laundry Machinery Corp. 143
American Lip Corporation 122
American Tradair Corp., Ekco Electronics Ltd. 131
Anton Electronic Laboratories, Inc. 168
Associated Nucleonics, Inc. 133
Atomics International, A Division of North American Aviation, Inc. 109, 150, 151
Automatic Switch Co. 123
Avery & Saul Company 76
Babcock & Wilcox Company, Atomic Energy Division 1
Baird-Atomic, Inc. 111
Barnes Co. W. F. & John 112
Barnstead Still & Sterilizer Co. 158
Blaw-Knox Co., Copes-Vulcan Division 148
Blickman, Inc. S. 145
Bristol Company 78
Byron Jackson Pumps, Inc. a subsidiary of Borg-Warner 65–68
Cambridge Instrument Company, Inc. 179
Cameron Iron Works, Inc. 59
Carlson Inc. G. O. 41
Central Research Laboratories, Inc. 30
Charleston Rubber Company 51
Chicago Bridge & Iron Company 71
Cleveland Hard Facing, Inc. 56
Consolidated Electrodynamics 49
Corning Glass Works 155
Crane Co. 32
Crawford Fitting Co. 8
Curtiss-Wright Corporation 62, 145
Davison Chemical Division of W. R. Grace & Co. 80
Delta Chemical Works, Inc. 154
Dyna-Empire, Inc. 191
E.M.I. Electronics Ltd. 118
Edgerton, Germeshausen & Grier, Inc. 171

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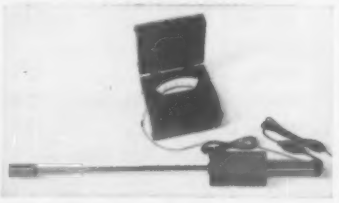

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Elcor Inc. 164
Eldorado Electronics 152
Electro Data Division, Burroughs Corp. 5
Evershield Products, Inc. . . . 169
Fansteel Metallurgical Corp. 79
Federated Metals Division of American Smelting & Refining Company 61
Fenn Manufacturing Company 43
Flanders Filters Incorporated 169
Gaertner Scientific Corporation 6
General Mills Mechanical Division 129
General Transistor Corp. . . 63
Gordon Co., Claud S. 138
Great Lakes Carbon Corp. . 152
Griscom-Russell Company . . 50
Hamner Electronics Co., Inc. 2nd Cover
Harvey-Wells Electronics, Inc. 145
High Voltage Engineering Corporation 141
International Nickel Company, Inc. 84
Interstate Industrial Uniform Rental Service Inc. 157
Isotopes Developments Ltd. 40
Jordan Electronics, a division of The Victoreen Instrument Co. 149
Kaiser Engineers . . . . 3rd Cover
Keithley Instruments Inc. . . . 42
Kelley and Company, O. G. 36, 37
Kinney Mfg. Division, New York Air Brake Co. 7
Kollmorgen Optical Corporation 117
Landauer Jr. & Company, R. S. 193
Leeds & Northrup Company 81
Lindsay Chemical Division, American Potash Corp. . . 44
Lockheed Aircraft Corp., Georgia Div. 182
Loma Machine Mfg. Co., Inc. 144
Los Alamos Scientific Laboratory 160
M & C Nuclear Inc. 2
Mallory-Sharon Metals Corporation 46, 47
Mallinckrodt Nuclear Corp. 10, 11
Marman Division, Aeroquip Corp. 113
Martin Company, The 130
Marvel-Schebler Products Div. Borg-Warner Corp. . 121
McGraw-Hill Book Co. 45
Michigan Chemical Corporation 179

Minneapolis-Honeywell ...119
Narda Ultrasonics Corporation, The.....170
National Aeronautics and Space Administration... 52
National Beryllia Corp.....165
National Carbon Company, Division of Union Carbide Corporation.....4th Cover
National Lead Company.. 83
New York Air Brake Co.... 7
Norton Company.....135
Nuclear-Chicago Corporation 58
Nuclear Development Corporation of America.... 16
Nuclear-Electronics Corp...173
Nuclear Enterprises, Ltd....139
Nuclear Materials & Equipment Corp.....114
Nuclear Measurement Corp. 116
Nuclear Service Laboratory.190
Nuclear Shielding Supplies & Service, Inc.....190
Nuclear Systems A Division of the Budd Company.. 64
Nucleonics.....14, 15
Oak Ridge National Laboratories-Isotopes Division (Union Carbide Corp.).126
Penberthy Instrument Co...130
Pergamon Press, Inc.....172
Philips Gloeilampenfabrieken N. V.....153
Picker X-Ray Corporation.. 9
Pintsch Bamag..... 77
Radiation Counter Laboratories Inc..... 29
Radiation Instrument Co...178
Radiation Instrument Development Laboratory, Inc. 194
Radiochemical Centre, The.156
Rawson Electrical Instrument Company 192
Ray Proof Corporation....125
Reinhold Publishing Corp..137
Riggs Nucleonics Corp.....181
Robertshaw-Fulton Controls Company, Fulton Sylphon Div. 136
Rocketdyne, A Division of North American Aviation, Inc. 120
St. John X-Ray Laboratory.190
Searchlight Section...183–190
Simmons-Boardman Books.164
Solar Aircraft Company... 60
Spencer Chemical Company 34, 35
Stonite Coil Corp.....191
Superior Steel Division of Copperweld Steel Company 53

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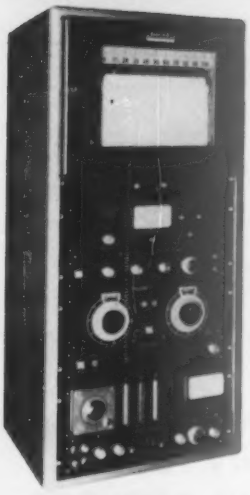

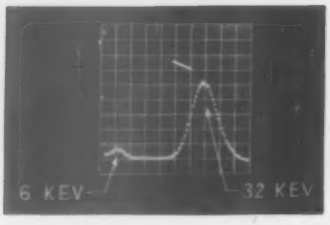

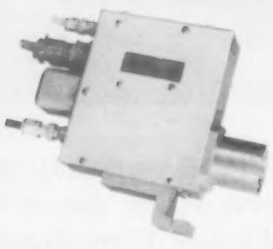

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Technical Associates. 134
Technical Measurement Corp. 70
Texas Instruments Incorporated 33
Tracerlab Inc. 54, 55, 154, 175, 178
Tube Methods Inc. 176
United Nations. 177
United States Radium Corp. 163
United Shoe Machinery Corp. 12, 13
University of California. . . 134
Vard Inc. 31
Vickers Research Limited. 38, 39
Victoreen Instrument Company, The. 147
Vitro Corporation of America 174
Wall Colmonoy Corporation 192
Westinghouse Electric Corp. Electronic Tube Div. 73
Westinghouse Testing Reactor 127
Westinghouse Atomic Power Dept. 146
Westronics Incorporated. . . 132
Wood Counter Laboratory N. 165
Zallea Brothers. 75
Zirconium Corporation of America 192

•

PROFESSIONAL SERVICES. . 190

CLASSIFIED ADVERTISING
F. J. Eberle, Business Mgr.

EMPLOYMENT OPPORTUNITIES 182–190
EQUIPMENT (Used or Surplus New) For Sale. 183
SPECIAL SERVICES. 183
Contract Work
Argonne National Laboratory. . . 187
Atomics International, Div. of North Amer. Aviation Inc. . . . 188
Atomic Power Development Assoc., Inc. 186
Battelle Memorial Institute. 183
Bethlehem Steel Company. 184
Calvert Electronics. 183
Esquire Personnel Inc. 184
General Electric Company 185, 189, 190
Lockheed Aircraft Corporation. . 182
Monmouth Radio Laboratories. . 183
National Lead Company. 188
North Carolina State College. . . 186
Nuclear-Chicago Corporation. . . 186
Tracerlab Inc. 183

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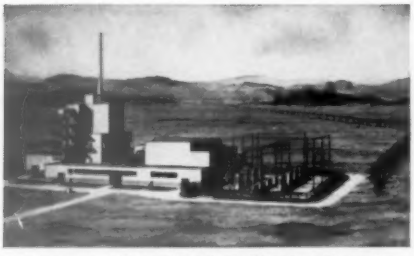

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